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ABSTRACT

In order for teachers to improve their effectiveness, they must be knowledgeable about student learning, curriculum developments, and new instructional approaches. This document discusses learning, curriculum reform, and teacher improvement. Chapter 1, "The National Perspective" (Stephen J. Fitzsimmons and Larry C. Kerpelman), prepares the way for subsequent chapters to examine in detail what is known about ways of improving the quality of science and mathematics education provided by teachers of our nation's youth. In chapter 2, "The Context of Science and Mathematics Inservice Education Programs," Iris R. Weiss sets the context for understanding where science and mathematics preparation stands at the K-12 levels in the United States. In chapter 3, "Cognitive Aspects of Learning in Science," Jose P. Mestre provides a review of the research on cognitive aspects of learning science concepts and principles. In chapter 4, "Approaches to the Science Curricula for Grades K-12," Senta A. Raizen reviews the state of science curricula, their objectives, and recent movements for reform. In chapter 5, "In-service Education Models for Enhancing the Teaching of Science," Richard J. Shavelson and colleagues lay out a bidimensional approach to understanding and planning inservice education for science teachers. In chapter 6, "Learning and Teaching Mathematical Sciences: Implications for Inservice Programs," Penelope L. Peterson describes four assumptions about learning that are central to contemporary theory, research, policy, and practice in mathematics education. In chapter 7, "Questions about the Mathematics Curricula for Grades K-12," Thomas A. Romberg provides a thorough discussion of what curriculum reform in mathematics must involve and the rationale for such reform. In chapter 8, "In-service Programs in Mathematics Education," Thomas J. Cooney discusses inservice models for mathematics educators, paying particular attention to the philosophical and epistemological underpinnings for such models. Finally in chapter 9, "Observations and Considerations," Roger G. Baldwin and Frances Lawrenz discusses the national need for a teacher enhancement system that supports the reform movement in science and mathematics education. (ZWH)

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Division of Research, Evaluation, and Dissemination * Report

TEACHER ENHANCEMENT FOR ELEMENTARY AND SECONDARY SCIENCE AND MATHEMATICS: STATUS, ISSUES, AND PROBLEMS

Stephen J. Fitzsimmons and
Larry C. Kerpelman, Editors
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Finally, our special appreciation goes to the authors of those chapters, who drew upon their extensive experience to contribute the many ideas about improving in-service science and mathematics teacher education in the United States that this book provides.

PREFACE

Over the past decade, American citizens have received considerable "bad news" about the educational performance of the youth of the United States. Attention has been focused particularly on the quality of student performance in two specific curriculum areas — the sciences and mathematics. The average performance of United States students in physics, chemistry, biology, calculus, and other advanced science and mathematics subjects falls well below that of students in most of the European and Asian countries that are our main competitors in the world marketplace.

The world is rapidly becoming one marketplace. Market dominance will go to those nations whose work forces produce the goods and services required by the wider world most cost-effectively and with the highest quality. Chancellor Helmut Schmidt of the Federal Republic of Germany recognized in the mid 1970s that advanced industrial countries would only be able to compete if they concentrated their human resources in "high value-added" goods and services. While not all high value-added jobs in the future will require scientists and engineers, a great majority may require reasonable proficiency in science, mathematics, engineering, computing skills, and general literacy. This situation will be compounded as individuals change careers or employers more often and thus encounter job competency requirements more frequently. Parallel to these developments in the private sector, public policy decisions on energy, the environment, health, and many other areas of life increasingly require a basic understanding of highly technical subjects. Indeed, in what is referred to as "the problem of democracy in a highly technological society," citizens' understanding of, and competence in addressing, complex mathematical and scientific issues is seen as critical for a fully functioning democracy.

There are many underlying causes — economic, social, and cultural — for poor educational performance by today's students. The schools, by themselves, cannot overcome significant problems in the families and neighborhoods in which children are raised. Other community, state, and federal efforts supportive of education, even if not "educational" in themselves, are necessary. It is clear, however, that the schools must be an important part of the solution.

There are some encouraging signs of progress in science and mathematics competency. Citizens and their representatives in government — local, state, and federal — appear to recognize the seriousness of these problems, and a general consensus is emerging that something needs to be done, although disagreements remain on what to do and how to pay for it. Further, American school systems are capable of producing very high quality graduates; we see evidence of it throughout the nation. Finally, increasing attention is being given to how students most effectively learn, to the quality of materials from which they learn, and to new techniques designed to improve the quality of teaching.

The three topics reflected in the foregoing discussion — learning, curriculum reform, and teacher improvement — are addressed in this book. But the overarching theme of this book is teacher improvement. In order for teachers to improve their effectiveness, they must be knowledgeable about student learning, curriculum developments, and new instructional approaches. It goes without saying, too, that the educational structure must support teachers' efforts to learn about, and then to apply, effectiveness-enhancing concepts and practices. Teachers must be provided with an environment and support system consistent with the level of professionalism of which they are capable — a level that is necessary for relieving the science and mathematics "ills" of the country.

It is not the purpose of this book to propose how to identify, and then solve, all of the nation's problems that contribute to poor student performance. Nor do we attempt to examine all aspects of school system operation. Rather, we restrict our focus here to a significant component of the educational process — the teacher — and more specifically to the ways to improve teacher preparation and the quality of instruction through the provision of effective in-service education programs.

We begin with a brief overview of what we know about the nation's problems in education and how efforts to improve the education provided by teachers in the nation's schools are now becoming a significant focus.

The next three sections of the book address three common topics in science and mathematics education, respectively. First, we address the question of the nature of learning itself — defining the process of acquiring new information (and often discarding incorrect perceptions previously held). A teacher who understands how learning takes place will do a better job of assuring that it does take place. Second, we examine how curriculum reform is occurring, why it is occuring, and with what substantive and instructional changes. Developers of teacher enhancement programs ought to know about new themes in curriculum reform that are emerging from recent policy and development work in science and mathematics education. The teachers who participate in teaching enhancement programs will, in turn, benefit from these reforms and help advance them. Finally, we examine how science and mathematics instruction may be improved through effective in-service teacher education. Those educators responsible for planning that activity can benefit from what we have learned about what works in teacher enhancement.

The book concludes with an examination of the program and policy implications that the preceding chapters suggest. With further improvements in the education of our teachers — in whose hands we have entrusted the education of our children — the understanding of science and mathematics by our children and youth will no doubt advance.

PART ONE: INTRODUCTION AND CONTEXT

1 THE NATIONAL PERSPECTIVE

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"By the year 2000, U.S. students will be first in the world in science and mathematics achievement."

(Federal Coordinating Council for Science, Engineering, and Technology, 1991, p.1)

The level of achievement of U.S. students in science and mathematics, as measured by a number of international assessments, is currently well below that of most industrial nations. Moving it to pre-eminence by the year 2000 is an extremely ambitious goal. If we want to improve the relative international standing of U.S. students, as well as meet our nation's future need for a high quality work force, considerable improvement is needed in the quality of the science and mathematics education provided to our elementary and secondary school students. To achieve this goal in the short term, intensive efforts must be made to enhance the knowledge and skills of the 2.2 million elementary and secondary school teachers who deliver science and mathematics education in this country.[1] The purpose of this book is to examine how to improve teaching in these fields, and to contribute to thinking and policy formulation on a number of major programs in support of educational reforms.

The principal focus of this book is teacher enhancement programs, especially in-service education programs designed to improve the quality of science and mathematics teaching in our schools. Many teachers have not had sufficient training or experience to meet their responsibility. Even among those with the appropriate training and experience, their knowledge of both subject matter and effective teaching techniques may be outdated. Especially in the sciences, the growth of knowledge over the past several decades has been explosive.

In-service education programs can do much to improve the quality of instruction provided by teachers to their students. In addition, such programs can go a long way to support national science and mathematics educational reform efforts. In the context of these efforts, teachers will need even more professional development to alter their teaching practices, engage their students, adopt and adapt curricula, and do all the other things called for by these curriculum reform efforts. The National Science Foundation has made it clear that issues in science and mathematics education need to be confronted by systemic responses, and teacher in-service education is one highly integral component of that response.

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[1] *The National Science Foundation generally uses the figure 2.2 million for the number of elementary and secondary school science and mathematics teachers in the United States (Federal Coordinating Council for Science, Engineering, and Technology, 1993); we use this number throughout this book.*

The areas of particular concern addressed here include examination of the cognitive aspects of learning science and mathematics subject matter, implementation of necessary curriculum reforms to enhance both the subject matter and the process of learning in these fields, and optimization of in-service education for our nation's science and mathematics teachers.

By integrating information from a variety of sources in a concise, nontechnical style, we hope to make the most current data and thinking on education for science and mathematics available to a broad audience of educators, policy makers, and concerned laymen. By focusing on one important aspect of this overall problem — in-service education of science and mathematics teachers in grades K-12 — we hope to make a significant contribution to improving the quality of teaching, and through it U.S. students' levels of competence, in science and mathematics. And we hope that this book will stimulate backing for more encouragement and support by administrators — time, funds, communication vehicles — to promote teachers' participation in in-service education, and support their professional growth.

This book is directed specifically to those in universities and school systems who offer in-service education to science and mathematics teachers. Other intended audiences include school boards and school district administrators responsible for the quality of instruction and determination of curricula in science and mathematics; federal agency program staffs involved in K-12 teacher preparation and enhancement; policymakers concerned with issues in teacher education; staffs of science and mathematics professional societies; and citizen groups concerned with the condition of American education. We believe that this book addresses a national need, and we hope that it stimulates thinking, concern, and action on this critical problem.

This chapter prepares the way for subsequent chapters to examine in detail what is known about ways of improving the quality of science and mathematics education provided by teachers of our nation's youth. We begin this chapter with a brief discussion of the need for nationwide educational reforms, a description of a series of national goals established by President Bush and the nation's fifty governors, and then a more specific discussion of some of the problems that need to be addressed. The chapter concludes with some remarks regarding the interdependence of learning in the sciences and mathematics and previews of subsequent chapters in this book.

1.1 The National Need to Improve Science and Mathematics Education

Over the past decade, citizens of the United States have become increasingly aware of and concerned about the quality of education provided to the nation's youth and the resultant state of their intellectual skills. The U.S. press has reported considerable information on the nature of the problems, as presented by various commissions and public interest groups. Several factors have pushed concern about the quality of the nation's science and mathematics education to the fore.

First, test results of *student performance* in science and mathematics, geography, and related subject areas indicate that America's students perform poorly compared with students of other Western industrialized countries and Asia (International Association for the Evaluation of Educational Achievement, 1988; LaPointe, Askew, & Mead, 1992; LaPointe, Mead, & Askew, 1992). While national tests may not serve to measure accurately either the depth or breadth of what we mean by scientific and mathematical literacy, the test results are used to arouse concern.

Second, the United States appears to be losing its *competitive advantage* in the world economy, and a portion of this loss relates to technology-intensive industries and services. Notably, many technologies invented in the United States have subsequently been developed and successfully marketed by foreign firms.

Third, the nation's *future economic development* will be critically dependent upon preparing an adequate work force to serve in our nation's technology-intensive industries, government agencies, universities, health industry, and defense establishment. Related to these concerns, *the average citizen needs to understand science and mathematics better* in order to make intelligent decisions about such issues as health care and its costs, the environment and its degradation, and employment and careers. As discussed by Thomas Romberg in Chapter 7 of this book, the matter goes beyond simply fostering understanding to achieve better decision making. It also involves democratic competence in a highly technological society where the average citizen must have the knowledge to analyze and evaluate technological developments.

The nation faces a multifaceted problem that causes concern about long-term labor force requirements in science, mathematics, and engineering. As a result of a decline in birth rates among American families during the 1970s and early 1980s, the size of the college-age population has been declining for almost a decade. There are fewer Americans available from which the college pool is being drawn. At the same time, the participation rate of United States students electing to pursue science and engineering graduate training at U.S. institutions of higher education is on the decline. Women, minorities, and persons with disabilities represent a part of the U.S. population that is growing but remain underrepresented as science and mathematics majors at our colleges and universities All of this is occurring as we enter a more technologically-intensive, global economy in the twenty-first Century.

1.2 National Goals for Educational Improvement

The Federal Coordinating Council for Science, Engineering, and Technology [FCCSET] report *By the Year 2000: First in the World* (1991) provides a concise summary of the significant challenges faced by the nation in its efforts to improve the quality of science and mathematics education, as discussed above. It points out that the responsibility for improving the quality of the nation's schools is distributed among federal, state, and local governments and must involve educators and parents, business and industry, professional associations, and community organizations. While the federal government accounts for only 6 percent of the nation's K-12 educational budget, it can play an important role in highlighting national problems, mobilizing national support, and funding programs that offer unique solutions.

In the Goals 2000 Act, three relate to the quality of U.S. science, mathematics, and engineering education:

3) By the year 2000, American students will leave grades four, eight, and twelve having demonstrated competency in challenging subject matter including English, mathematics, science, history, and geography; and every school in America will ensure that all students learn to use their minds well, so they may be prepared for responsible citizenship, further learning, and productive employment in our modern economy.

5) By the year 2000, U.S. students will be first in the world in science and mathematics achievement.

6) By the year 2000, every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship.

Since their promulgation, these goals have been the focus of a variety of efforts at the local, state, and federal level designed to improve many aspects of the nation's K-12 education. Irrespective of the goals of such educational reforms — or their source — a host of problems remains to be addressed if the nation is to accomplish significant improvements. In the following section, some of the key considerations that motivate educational reform are discussed.

1.3 The Educational Problems to Be Addressed

Five key issues underlie the concerns facing present-day science and mathematics education: student performance, involvement of underrepresented groups, quality of teaching, national economic competitiveness, and public science literacy.

Student Performance

As the nation's economic base becomes increasingly dependent on technology, U.S. students' lack of achievement and participation in science and mathematics should be a source of growing concern. Recent studies discussed below support the proposition that our schools are producing large numbers of graduates who lack the problem-solving ability and higher-order thinking skills; at the same time our economy increasingly needs people with these skills if it is to maintain its international competitiveness.

One indicator of U.S. students' achievement levels in science and mathematics subject matter is their relatively poor performance in comparison with their counterparts in other industrialized countries. The International Assessment of Educational Progress (Lapointe, Askew, & Mead, 1992) revealed that, among 13-year-old students in 15 countries around the world — industrialized and newly industrialized, high- and mid-level on the economic development scale — U.S. students placed third from last in science achievement. Moreover, among 13-year-old students in schools that emphasized the sciences in the same 15 countries, U.S. students ranked third from last in physics, fourth from last in earth and space sciences, and in the bottom half in the life sciences (Lapointe, Askew, & Mead, 1992).

In mathematics, U.S. 13-year-old students scored next to last overall in mathematics achievement and below the 15-country average. Moreover, among students in schools that emphasize various aspects of mathematics in the same 15 countries, U.S. students ranked third from last in measurement, second from last in geometry and in algebra, and among the bottom five in numbers and operations and in data analysis, probability, and statistics (Lapointe, Mead, & Askew, 1992).

A variety of factors may account for the relatively poor performance of America's youth. According to the 1991 FCCSET report, "Nearly 30% of our high schools offer no courses in physics, 17% offer none in chemistry, and 70% offer none in earth or space science" (p. 5). A contributing reason for this may be, as Iris R. Weiss indicates in Chapter 2 of this book, high school teachers' relatively sparse college-level coursework preparation in these areas.

Even for those students who do have the opportunity to take courses in these areas, numerous studies (e.g., Goodlad, 1984) have held that using textbooks as the mainstay of course work (as compared with other, more active learning activities) impedes students' learning of science and mathematics. Students' early exposure to science and mathematics — both prior to entering the school system, and throughout the elementary and middle-school years — is deemed to be seriously impaired by heavy reliance on listening and reading as opposed to thinking and doing.

The National Science Board (1991), in *Science and Engineering Indicators: 1991*, reviewed a range of up-to-date assessments regarding student performance. While documenting a number of problems, the report also contains some bright spots. In both science and mathematics, test scores showed some improvement during the 1980s, albeit not in a uniform fashion. While 9- and 13-year-olds attained scores that returned to the higher performance levels of two decades ago, 17-year-olds failed to reach their earlier levels. Black and Hispanic students showed even greater relative gains than their white counterparts but still had consistently lower achievement levels than whites. The gains achieved by students were uneven and appeared to be mostly in lower-level skills and basic concepts.

The same report further showed that only 5 percent of 12th graders demonstrated an adequate understanding of reasoning and problem-solving processes in mathematics subjects; 95 percent failed to achieve the proficiency level expected for college entrance-level work. Among 12th graders, fewer than one in four male students, and one in 10 female students, expressed an interest in science or engineering careers. Among those scoring above the 90th percentile on the SAT Quantitative Scale in 1990, only 45 percent expressed an interest in such careers.

Underrepresented Groups

Underrepresentation among certain segments of the U.S. population — women, blacks, and Hispanics — is a chronic problem in science and engineering higher education.[2] This problem may be influenced, among other things, by K-12 academic performance. According to the National Science Board, over the past decade, "Average science proficiency among blacks and Hispanics remained far below that of white students" (1991, p. 17). While the differences in proficiency appeared to narrow somewhat between 1977 and 1986, it held constant again between 1986 and 1990. This report also noted that female students in three K-12 age groups have performed more poorly than males over the past two decades; the difference in performance appears to worsen for females as they advance to high school.

Miller et al. (1990) examined the data from the Longitudinal Study of American Youth, based on a probability sample of 6,000 middle and high school students. They report that one-third of all male students and one-quarter of all female students report an interest in science, mathematics, and engineering careers in the 7th grade, but by the 12th grade, these figures drop to one-quarter of all males and one-tenth of females. The decision to pursue such a career, moreover, appears to be the result of a wide array of factors, including parental encouragement, parental resources, student gender, and persistence in mathematics.

Despite the fact that blacks and Hispanics make up 20 percent of the U.S. population, they represent only 6 percent of Ph.D's in science and engineering. Female participation, as a percentage of all Ph.D's, rose from 22 percent to 28 percent during the 1980s, but females continue to be underrepresented, most notably in the physical sciences (National Science Board, 1991).

Inasmuch as a large percentage of the new entrants into the American labor force for the foreseeable future will consist of women, minorities, and foreign nationals, the protracted problem of underrepresentation could take a serious toll on the nation's future economic development in high technology fields.

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[2] *Participation rates among Asian Americans is disproportionately high vis-à-vis their representation in the U.S. population; for this reason, the NSF does not consider them an "underrepresented group."*

Teachers

The ability to teach effectively must be viewed in the context of the crisis in the educational system as a whole. Communities throughout the nation, faced with serious budget problems, have been forced to limit the hiring of new teachers.

In addition, schools suffer from or reflect the serious problems of society, including inadequate family support of students' educational development, increasing numbers of disadvantaged children and children from single parent families, and disruptive social behaviors in both the communities and the schools.

Within this larger context, it is hardly surprising that fewer and fewer college students are electing to pursue a teaching career. Many states now require their high school teachers to obtain degrees in the science or mathematics area in which they intend to teach. While this is likely to improve the competence of those who go into teaching in these subject areas, it may decrease the number of people who will choose to do so.

Data available on teacher retention are not encouraging. Weiss and Boyd (1990) report that an average of 13,000 science and mathematics teachers leave the field each year. The *By the Year 2000* report (FCCSET, 1991) states that, among students who enter teaching careers, 20 percent leave during their first year, while more than half leave by their sixth year.

Thus, the nation's schools face three problems simultaneously: teachers face the prospect of many social and economic ills intruding increasingly in their classrooms; many prospective teachers are discouraged from seeking such a career; and still others already teaching are choosing to leave the field.

A number of studies are cited by the National Science Board (1991) regarding the association between teacher qualifications and quality of instruction. For example, a study by Shavelson, McDonnell, and Oakes (1989) concluded that the qualifications of science and mathematics teachers largely determines the quality of instruction their students receive.

Turning to instructional methods, psychologists and education researchers have demonstrated that student learning and motivation increase with hands-on learning activities; yet in many classrooms, lectures and textbooks are the teachers' instructional mainstays. Fewer than half of 7th graders and one-quarter of 11th graders report "being asked to suggest hypotheses or interpret data — two fundamental skills in science" (Mullis & Jenkins, 1988, p. 98). In a more recent study, almost half of 8th grade students, and one-third of 12th graders, said their teachers never asked them to write-up a science experiment (Jones, Mullis, Raizen, Weiss, &

Weston, 1992). Since interest in science and mathematics may be instilled early in students' education, instruction in these fields that permits (or even encourages) student passivity institutes the notion that science or mathematics are not terribly exciting, leading to avoidance of these fields by students in their college curriculum and subsequent careers.

In order to increase the quality of student performance in the coming years, teachers must be well versed in the subject matter, have the skills for teaching the subject matter, and provide ways of motivating and involving students in their classrooms and laboratories. High quality in-service programs for teachers are one important way to enhance these skills. Improved quality of instruction, in turn, will benefit the students receiving that instruction. Moreover, teachers who enhance their subject matter and teaching skills may be more likely to experience job satisfaction, advance their professional careers, and stay in a teaching role. Finally, teachers who receive in-service education in new science and mathematics teaching and curriculum approaches are the ones who will advance educational and curricular reform in these fields.

Economic and Scientific Competitiveness

The nation's work force is in the process of undergoing significant changes, with employment declining in many of the more traditional manufacturing sectors. Moreover, in those high value-added manufacturing industries where employment may increase, extensive technical knowledge is typically required of workers. In the case of technology-intensive jobs in the service sector that pay well and offer a promising economic future (e.g., in telecommunications and computers) extensive mathematical and technological skills are required.

It is extremely difficult to construct accurate forecasts of the demand for science, mathematics, and engineering graduates due to the fact that total demand is a function of numerous micromanagement decisions among diverse firms over time. Nevertheless, trends on the supply side are clear. The size of the total college age population has been on the decline during the 1980s and will continue to decline through the late 1990s. The participation rates among a key source of supply (white male students) has been declining and is not being offset by increases in female and minority participation. According to the *By the Year 2000* report, only 6 of every 4,000 seventh graders will eventually receive a Ph.D. in science or engineering.

In the nation's graduate schools, decreases in the proportion of U.S. citizens majoring in science, mathematics, and engineering fields may be offset somewhat by increases in foreign student enrollment. Today, more than half of all mathematics and engineering doctorates in the U.S., and more than 30 percent of science doctorates, are awarded to foreign citizens (National Science Board, 1991). It is likely that, as conditions in other parts of the world improve, an increasing percentage of these students may choose to return to their native lands as opportunities become available.

To the extent that there are too few sufficiently qualified entrants into the U.S. labor force to meet the demands of business and industry for technical positions over the next two decades, we can expect adverse impacts on U.S. competitiveness in the world.

Public Science Literacy

Implicitly, many of the concerns cited above are directed toward the preparation of scientists, engineers, and other technically skilled workers. But the issues raised are also significant for the larger society. In an increasingly technology-intensive society, where issues of health, environment, energy, communications, transportation, and education all require a keen understanding of technological and scientific concepts, informed decisions by the electorate will require a higher level of public scientific and quantitative literacy. In an increasingly competitive job market, scientific and mathematical competence will also be an important factor in career entry and mobility. And in a society where the typical wage earner may change jobs a number of times during his or her working life, competence in these fields will open up a larger number of job opportunities. Finally, better-educated parents are more likely to encourage their children to strive for scientific and mathematical competence, reinforcing the capability of the citizenry to make decisions about important technological matters without deferring to the experts. It is within this broader societal context that the NSF supports a broad range of initiatives designed to improve the overall quality of the nation's scientific, mathematics, and engineering education and literacy.

1.4 The Contributions of the Department of Education and the National Science Foundation to Teacher Enhancement

While it is widely acknowledged that improvement in education will have to occur largely through state- and local-level initiatives, the federal government is in a position to make important contributions to the overall education system. Sixteen federal government departments and individual agencies contribute to the achievement of these goals.[3] The principal federal funding requests for a variety of K-12 programs come from the U.S. Department of Education and from the National Science Foundation. Major components of the budgets of both agencies are targeted to the instructional work force.

Of particular note with regard to science and mathematics teacher enhancement in the Department of Education is its Eisenhower Mathematics and Science Education Program. For the 1989-90 reporting period, this program's funding was $124 million. Of that amount, 68percent went for "flow through" funds to school districts, supporting primarily "low intensity" in-service education (six hours per participant annually) fairly evenly distributed across all levels of K-12 education. Another 24 percent of the Eisenhower funding was earmarked for institutions of higher education, primarily for in-service education for practicing teachers at the K-12 level (again, fairly evenly distributed across elementary, middle, and high school levels). These higher education-based projects "offer teachers many more hours of exposure to content and pedagogy, averaging 60 hours per participating teacher." (Knapp, Zucker, Adelman, & St. John, 1991).

The National Science Foundation has a broad legislative mandate to strengthen science and mathematics education in the United States (see the National Science Foundation Act of 1950 [as amended]). Its programs cover natural and social sciences, engineering, and mathematics, at all education levels (kindergarten through postgraduate studies).

The National Science Foundation has five major educational objectives (National Science Foundation, 1993, p.11):

- to help ensure that a high-quality school education in science is available to every child in the United States, sufficient to enable those who are interested and talented to pursue technical careers at all levels, as well as to provide a base for understanding by all citizens;

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[3] *These 16 federal departments and independent agencies are the Departments of Agriculture, Commerce, Defense, Education, Energy, Health and Human Services, Housing and Urban Development, Interior, Justice, Labor, Transportation, and Veterans Affairs, and the Environmental Protection Agency, National Science Foundation, National Aeronautics and Space Administration, and the Smithsonian Institution.*

- to help ensure that the educational pipelines carrying students to careers in science, mathematics, and engineering yield numbers of well-educated individuals sufficient to meet the needs of the U.S. technical workforce;

- to help ensure that those who select scientific and engineering careers have available the best possible professional education in their disciplines;

- to help ensure that opportunities are available at the college level for interested nonspecialists to broaden their science backgrounds; and

- to support informal science education programs and to maintain public interest in and awareness of scientific and technological developments.

The NSF strategy is to play a catalytic role that will enhance local efforts, bring to bear the skills and knowledge of the nation's best scientists and educators, and engage the resources of both the public and private sectors. The Foundation encourages partnerships in the projects it supports, including cooperative involvement among colleges and universities, local and state education agencies, cultural and professional institutions and societies, and business and industry.

The National Science Foundation also seeks to leverage the application of its resources and is strongly committed to the principle of cost sharing in its projects, both as evidence of a project's importance to the proposing institution and as an indication of continuing commitment and long-term impact. It is especially concerned about the underrepresentation of women, minorities, and the physically disabled in careers in mathematics, engineering, and the sciences. Projects involving members of these groups as principal investigators or staff, or as the target audiences, are especially encouraged.

Within the NSF, the Directorate for Education and Human Resources (EHR) designs and funds programs and projects that support the NSF's educational mission. The Division of Elementary, Secondary and Informal Education, a part of EHR, is charged with the responsibility of addressing persistent educational problems in the K-12 and informal science education areas. The Teacher Enhancement (TE) Program seeks to improve, broaden, and deepen the disciplinary and pedagogical knowledge of teachers, administrators, and others who play significant roles in providing quality science, mathematics, and technology education for students from prekindergarten through grade 12 [pre-K-12].[5] To this end, TE promotes (1) systemic change, (2) teaching enhancement (in-service teacher development), (3) dissemination, and (4) other activities such as conferences and professional-materials development. The program encourages proposals that focus on the areas of greatest educational need and that are submitted by individuals or groups who have not previously applied for NSF support.

Each project, while implementing educational improvements in different ways, serves the same vision of exemplary education in science, mathematics, and technology. This vision is based on (1) recognition of the critical role outstanding teachers play in promoting competence, interest, and enthusiasm for study in these fields; (2) the need for school counselors, parents, community leaders, and others to provide a supportive environment; and (3) the requirement that school administrators and educational leaders commit themselves and the resources they control to ensuring excellence in education for all students.

1.5 The Teacher Enhancement Program Evaluation, 1984-89

During 1991 and 1992, the NSF carried out an evaluation of the Teacher Enhancement Program to assess its effectiveness over the 1984-89 period and to make recommendations regarding future program activities. While the current program emphasis is on expanding impacts, developing teacher leadership, and promoting systemic reform, in the earlier period the program focused primarily on methods of educating teachers and on developing new materials for effective teaching of science and mathematics. It also focused on fostering cooperation among organizations concerned with improving local, state, regional, and national science and technology education, as well as on providing opportunities for the professional development of all teachers who participated.

Professional development is a major focus of the TE program. The promotion of significant collegial relationships that allow the sharing of classroom experience and ideas with others is an important function of TE projects. The TE projects also provide information and incentives for participants to continuously construct and reconstruct the theoretical and practical bases for their teaching. Related to this, TE projects stimulate an emphasis on teaching practices oriented toward problem solving and on constructive methods sensitive to the development of individual students.

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[5] *The National Science Foundation also has a program supporting the preservice training of teachers. This program is administered by the EHR Division of Undergraduate Education.*

Principal Investigators (PIs) of TE projects are expected to select as participants those public and private school teachers of science and mathematics at all levels of education with a demonstrated capacity and willingness to help colleagues needing instructional assistance, thus spreading the impact of the projects to other teachers who have not had the opportunity to participate. The PIs are also expected to assist in establishing and maintaining the commitments of participants' home school systems to support their continuing leadership efforts.

Over the 1984-89 period, 599 projects were funded throughout the United States with a total commitment of $160 million. The program supported the training of an estimated 63,000 science and mathematics teachers under TE awards made between FY 1984 and FY 1989 — approximately 3 percent of all K-12 teachers in the United States who had responsibility for teaching science or mathematics.

As part of the evaluation study, a survey was conducted of all PIs who received grants to conduct TE projects between FY 1984 and FY 1989 (Fitzsimmons, Carlson, Burnham, Heinig, & Stoner, 1992). Seventy-six percent of the PIs responded to the survey. The typical TE project served approximately 100 teachers. Teachers who were members of minority groups made up 18 percent of all participants, while more than half of all participants were female. The survey also showed that typical in-service training focused principally on biological and physical sciences and mathematics, with other sciences covered to a lesser degree.

According to PIs, effective in-service training projects emphasized hands-on activities (e.g., working with scientific models, materials, and techniques in the laboratory), field trips (e.g., to museums and zoos), and the use of cooperative learning groups (e.g., small groups of teachers working together to formulate and solve problems or analyze data). In addition, effective instructional methods were viewed to include the development of student instructional materials (e.g., curriculum materials for course modules), small group discussions (e.g., on effective teaching strategies for a particular concept), use of resource people (e.g., making use of local museum staff in classroom visits), instructor demonstrations, and peer teaching. Role-playing, lectures, computer-assisted instruction, library research, and films and videos were generally seen as less valuable instructional devices. An important exception, however, was that lectures were seen by the PIs as being most effective for improving content knowledge.

Many of the projects provided the opportunity for teachers to share and work together in local or regional settings to improve their own teaching under the guidance of the project staff. According to the PIs, participants established continuing collaborative partnerships with faculty members of schools, colleges, and universities, as well as with personnel from a variety of other public and private organizations. Representatives of museums were an especially important resource to TE projects. The projects gave special attention to increasing student access to careers in science, mathematics, and technology by reaching teachers who are serving populations underrepresented in the sciences as well as teachers serving economically disadvantaged communities. The PIs reported as one of their major accomplishments the expansion of participants' knowledge of concepts and applications of science and mathematics, as well as the deepening of participants' knowledge and application of improved teaching methods (including an emphasis on hands-on learning techniques).

The goals that a PI had for his or her TE project defined the instructional methods and materials used. For example, PIs who emphasized subject matter objectives used more formal teaching methods. Those PIs seeking to enhance teachers' knowledge of science and mathematics often used lectures, whereas those interested in integrating science and mathematics knowledge often made use of computer-assisted instruction methods and field trips. Those PIs who emphasized the improvement of teaching practices used more process-oriented teaching methods. For example, those who emphasized updating participants' teaching skills, or improving participants' abilities to enhance their students' interest in science and mathematics or their students' problem-solving skills, often used such teaching methods as cooperative learning, role-playing, simulations, and games. Those PIs working with high school teachers were more likely to use lectures, while those working with elementary school teachers emphasized more process-intensive instructional methods.

Project goals also determined whether or not instructional materials were developed. For example, those PIs with goals relating to teaching instruction had higher participant involvement in the development of instructional materials, involved the TE project staff in this process, and were more likely to use outside experts in the process as well.

Project outcomes were associated with the instruction methods used and the development of curriculum materials. Lecture methods, according to PIs, were associated with an increase in participants' subject matter knowledge. Computer-assisted instruction, field trips, library research, use of films and videos, and examination of instructional materials were also associated with the PIs' assessments of increases in participants' knowledge of content and teaching materials. On the other hand, more process-oriented teaching methods (such as the use of cooperative learning groups) were associated with the maintenance of longer-term contacts between PIs and participants.

The need to obtain a greater commitment from participants' school districts was the most frequently cited "lesson learned" in the survey. The PIs believed that participation of local school districts increased the probability of districts' adopting what teachers bring back to them. The most promising TE models, according to PIs, included the use of teachers to teach other teachers, hands-on methods (e.g., working with science models, laboratory experiments), and teacher pairs or groups to enhance learning (wherein teachers solve problems together or develop presentations). Were PIs to run another TE project, they indicated they would institute more follow-up support for participants, more hands-on activities, more extensive recruitment activity, more preproject planning, and greater efforts to influence the school districts and other local organizations.

1.6 Issues Addressed in This Book

Understanding, and then improving, the rationale and operation of in-service education programs in science and mathematics is an important challenge. The remainder of this book attempts, in a systematic way, to look at the issues from a fresh perspective and to garner insights that may help improve these programs.

In the remaining chapter of Part One of this book, Iris R. Weiss sets the context for understanding where science and mathematics teacher preparation stands at the K-12 levels, stands in the United States. She provides details of what teachers bring to the classroom by way of their coursework background, what they do in the classroom, and the implications of teacher participation and instruction for in-service education of these teachers. Her chapter looks at teacher preparation in terms of what the professional organizations indicate it should be, not just what it is, thus providing a set of standards against which to compare that preparation. In most fields and at most levels, teachers do not have the level and type of preparation to meet the standards of relevant professional associations. Further, she points out that many teachers are not being reached by in-service education, so that neither their subject matter capabilities nor their instructional techniques are being enhanced. Finally, Weiss points to various external "environmental" factors that impede teachers' effectiveness.

Part Two focuses on the conceptual background necessary to understand, develop, and improve in-service education in science. In Chapter 3, Jose P. Mestre provides a review of the research on cognitive aspects of learning in science — the thinking and perception skills needed to understand science concepts and principles. Current research from both the psychological and educational literature is examined for its implications on how to teach science. Mestre takes a strong position that a constructivist rather than a behaviorist approach is the most appropriate way to view learning in these fields. Given this assumption, he then examines science instruction practices at the K-12 level and points out the misalignments between these practices and the theory and research regarding how students learn. Finally, he proposes various approaches to reforming these practices, as well as textbooks and student assessment practices.

Chapter 4, by Senta A. Raizen, concerns the science curriculum. She reviews the state of science curricula, their objectives, and recent movements for their reform. She compares and contrasts U.S. science curricula with those of a sample of other industrialized countries and shows that many of the curricular objectives are similar. Raizen also provides a cogent summary of both the common goals and the common outcomes striven for by science curriculum reform efforts in the U.S. and other countries. Her chapter draws a distinction between the intended curriculum — what students are expected to learn — and the implemented curriculum — what they actually have the opportunity to learn. After discussing the large gaps between the intentions of curricular reforms and current classroom realities, the chapter concludes with a brief summary of federal programs designed to close these gaps.

In Chapter 5, in-service education models are examined and discussed. Richard J. Shavelson and his colleagues lay out a bidimensional approach to understanding and planning in-service education for science teachers. The two major dimensions they address — approaches to teacher enhancement and components of teacher enhancement programs — serve as the basis for a matrix which they flesh out through a searching discussion of illustrative applications in various school districts and states throughout the U.S. They discuss approaches to the evaluation of teacher in-service programs — both formative and summative — in the context of specific teacher enhancement programs, and offer critical questions to address in planning the evaluation of in-service programs.

Part Three examines the same topics as Part Two as they pertain to the teaching of mathematics. Penelope L. Peterson begins Chapter 6 by reviewing the shifts in assumptions about learning that have occurred in recent years. She describes four assumptions about learning that are central to contemporary theory, research, policy, and practice in mathematics education:

- Humans are knowledgeable learners.
- Learning involves the negotiation of shared meaning.
- Knowing is situated or contextualized.
- Assumptions about knowledge influence learning.

She shows us these new assumptions about mathematics teaching and learning in action through an analysis of the innovative teaching methods of one elementary school teacher. The implications of these assumptions, and the teaching-learning environment they seem to call for, are given full consideration in the concluding comments of her chapter.

Thomas A. Romberg provides in Chapter 7 a thorough discussion of what curriculum reform in mathematics must involve and the rationale for such reform. With a perspective on the historical development of schooling in the United States, he provides an understanding of the way mathematics has come to be taught and the curriculum has come to be structured. He calls for teachers to understand the rationale for curriculum reform — especially within a larger perspective of schooling reform — so that they can be active engines for change, both in what they teach and in how they teach. Examining the "reform vision" embodied in the National Council of Teachers of Mathematics' *Curriculum and Evaluation Standards for School Mathematics*, he makes a cogent argument for taking this vision to heart and taking active steps to accomplish the *Standards'* goals. These goals, he indicates, call for a radically different mathematics curriculum. He concludes his chapter with specific actions that need to be taken at the local curriculum-committee level to bring about curriculum reform.

Thomas J. Cooney's discussion in Chaper 8 of in-service models for mathematics educators pays particular attention to the philosophical and epistemological underpinnings for such models. He particularly stresses the point that teaching educators how to *teach* mathematics needs to be intimately tied to how students *learn* mathematics. His chapter examines both teachers' knowledge *of* mathematics and their beliefs *about* it, as essential elements in understanding how best to provide them with in-service education.

Part Four of this book attempts to take a step back and see what lessons can be learned from this volume. The last chapter, by Roger Baldwin and Frances Lawrenz, discusses the national need for a teacher enhancement system that supports the reform movement in science and mathematics education. It reviews factors needed to implement teacher enhancement programs capable of reshaping teacher behavior and transforming outmoded educational practices. The authors discuss implications and identify necessary actions for key players to take in the movement to strengthen science and mathematics education in general and enhance teacher in-service education in particular.

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THE CONTEXT OF SCIENCE AND MATHEMATICS IN-SERVICE EDUCATION PROGRAMS

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2.1 The Educational System in the United States

The task of in-service education is an enormous one, given the size and complexity of K-12 education in the United States. An estimated 2.6 million teachers provide instruction to roughly 46 million students in grades K-12 in the United States. About 90 percent of these teachers and students are distributed among the nation's 83,000 public schools in over 15,000 school districts; the remaining 300,000 or so teachers and 5 million students are at 27,000 private schools (National Center for Education Statistics, 1991).

While the federal government provides some modest support for K-12 education, most of the resources for education are provided by the states and localities. For example, in the 1986-87 school year, only 6 percent of the total expenditures for public elementary and secondary education came from federal sources; 50 percent came from the states and 44 percent from local sources (Davis, 1991).

The decentralized nature of the educational system in the United States has major implications for educational reform. Just as most resources devoted to education emanate from the states and localities, most of the key educational decisions are made at the state and local levels. The federal government's role in education is limited primarily to doing research (such as providing data on the status of education), ensuring that the needs of special populations (e.g., handicapped and economically disadvantaged students) are addressed, and developing and disseminating model programs. The federal government cannot dictate changes in curriculum, instruction, or teacher preparation. Decisions about such matters as teacher certification, in-service education, and requirements for high school graduation are typically made at the state level. Decisions about facilities, equipment, and supplies; selection of instructional materials; and hiring and assessing teachers are usually made at the local level.

2.2 The Science and Mathematics Teaching Force

According to the National Center for Education Statistics (1991), less than 5 percent of elementary teachers are science or mathematics *specialists*. The science/mathematics teaching force is an experienced one, with an average of 14 years teaching experience; more than one in five has taught for at least 20 years (Nelson, Weiss, & Capper, 1990). Most elementary school teachers are female (more than 95 percent in grades K-3 and about 80 percent in grades 4-6), while most high school mathematics and science teachers are male (Weiss, 1987). At a time when roughly 30 percent of the K-12 student population are members of minority groups, only an estimated 14 percent of elementary teachers and fewer than 10 percent of high school science and mathematics teachers are minorities (Nelson, et al., 1990).

2.2.1 Teacher Certification Requirements

While the percentage of teachers meeting state certification standards may be a useful indicator of the supply of teachers within a particular state, it is a poor indicator of teacher quality nationally because state requirements vary so greatly. For example, about one-fourth of the states have no course requirements in mathematics or science for prospective elementary school teachers; another ten states allow the degree-granting institution to establish its own certification requirements. Coursework requirements in the remaining states range from 3 to 12 semester credit-hours in science and 2 to 9 in mathematics (Council of Chief State School Officers, 1987).

The range in certification requirements is similarly quite large at the secondary school level. Two states require a major or minor in the subject; two others require a set percentage of total coursework to be in the field of specialization; and five allow the degree-granting institution to set certification requirements. Requirements vary widely in the remaining states, ranging from 12 to 45 semester credit-hours in the discipline. The situation is further complicated by the fact that teachers in some states may choose either to specialize in a specific science subject or to get "broad-field" certification that certifies them to teach any science subject (Council of Chief State School Officers, 1987).

A number of states also have requirements for continuing certification; typically teachers must earn six credits of coursework or the equivalent every five years to renew their certification (American Association of Colleges for Teacher Education, 1990). In some cases, states and districts tie teacher salaries to continuing education, with teachers advancing a salary grade if they earn a certain number of renewal credits.

2.2.2 Elementary School Teacher Course Background Preparation

Given the variations in certification requirements among the states, a more useful indicator of the qualifications of science teachers is course background preparation, regardless of their certification status. The National Science Teachers Association (NSTA) has recommended that elementary school science teachers have at least one course in the biological sciences, one in the physical sciences, and one in the earth/space sciences, as well as a course in the methods of teaching elementary school science (National Science Teachers Association, 1984). The 1985-86 National Survey of Science and Mathematics Education found that, while 88 percent of elementary school science teachers had completed a science methods course, and 86 percent had taken a college biology course, only 44 percent had college coursework in the earth/space sciences.[1] Seventy-two percent of elementary school teachers have had at least one course in the physical sciences, most often a "physical science" course rather than chemistry or physics. Only 34 percent of science teachers in grades K-6 met the NSTA standard of coursework in all three science areas (Weiss, Nelson, Boyd, & Hudson, 1989).

The National Council of Teachers of Mathematics (NCTM) has also established coursework standards for prospective elementary school teachers. The NCTM recommends that elementary school mathematics teachers have (1) a course on number systems through the rational numbers; (2) a course on informal geometry including mensuration, graphing, geometrical constructions, similarity, and congruence; and (3) a course on the methods of teaching mathematics (National Council of Teachers of Mathematics, 1985). In the analyses of the 1985-86 survey data, a teacher who had completed a course in mathematics for elementary or middle school teachers, a course in geometry for elementary of middle school teachers, and a course in methods of teaching mathematics was considered to have met these requirements. While 90 percent of elementary school mathematics teachers had taken a mathematics methods course, and 90 percent had completed a course in mathematics for elementary school teaching, relatively few elementary school teachers had taken other college courses in mathematics. Only

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[1] *The 1985-86 National Survey of Science and Mathematics Education was administered by mail to a probability sample of K-12 science and mathematics teachers. It is important to remember that the survey results are based on teacher self-reports; no attempt was made to validate the data (e.g., by analyzing teacher transcripts).*

18 percent of elementary school teachers met all of the NCTM's recommended standards (Weiss, et al., 1989).

Teachers' having completed college coursework in a discipline, however, is no guarantee that they will be prepared to teach it. In fact, there is considerable evidence that many elementary school teachers do not consider themselves equally qualified to teach all of the subjects they are expected to teach. The 1985-86 survey asked elementary school teachers to rate their qualifications for teaching mathematics, science, social studies, and reading. Most elementary school teachers indicated they felt very well qualified to teach reading and mathematics, but relatively few said they felt very well qualified to teach science (see Figure 2-1). Science subjects were the only ones in which more than 4 percent of the teachers indicated they felt "not qualified." The percentages were larger for the physical and earth sciences (23 and 22 percent, respectively) than for life sciences (11 percent) (Weiss, et al., 1989).

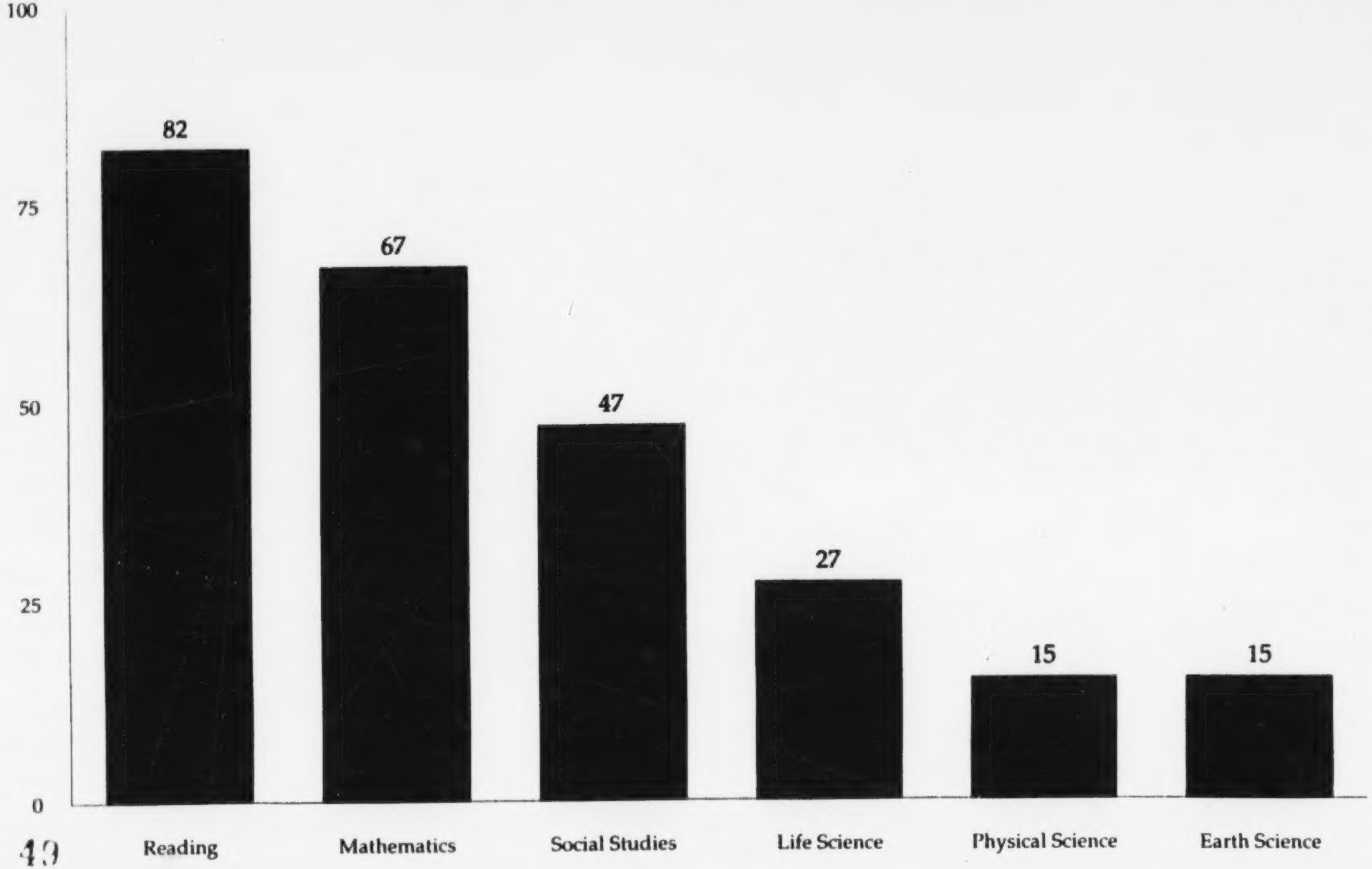
Further evidence of the perceived difficulty of the physical sciences was provided when teachers were asked to name a specific science topic they would find difficult to teach. A total of 63 percent of the elementary school science teachers listed physical science topics or simply "physics," "chemistry," or "physical science"; the most commonly cited specific topic was "electricity." A sizeable proportion (21 percent) listed topics in the earth sciences, but relatively few (7 percent) listed life science topics as difficult to teach (Weiss, et al., 1989).

2.2.3 Secondary School Teacher Course Background Preparation

Expectations for teacher course background preparation at the secondary school level are considerably higher than those at the elementary school level, with a number of prestigious groups recommending that prospective teachers first earn a degree in their subject and then get training in pedagogy. As can be seen in Figure 2-2, high school science and mathematics teachers are more likely than middle/junior high school teachers to have a degree in their discipline, and science teachers at the secondary school level are more likely than their mathematics teacher counterparts to have one or more college degrees in their discipline (Weiss, et al., 1989).

Figure 2-1

Percentage of Elementary School Teachers Feeling Very Well Qualified to Teach a Subject

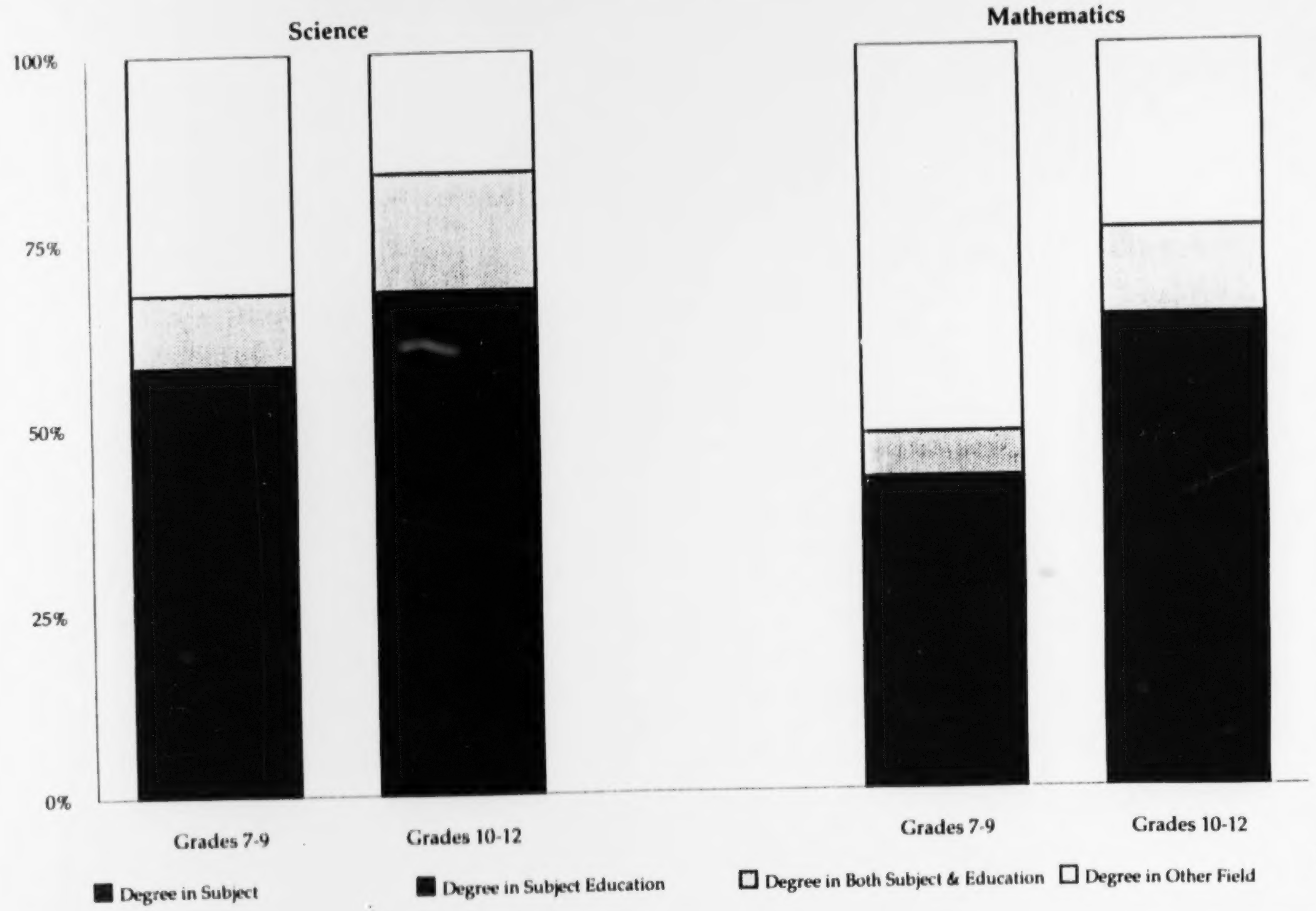


Source: 1985-86 National Survey of Science and Mathematics Education

(c) Horizon Research, Inc. 8/89

Figure 2-2

College Degrees of Science and Mathematics Teachers: 1985-86



Source: 1985-86 National Survey of Science and Mathematics Education

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Science Teachers

Based on data provided by teachers in the 1985-86 national survey, more than half of high school science teachers, and four out of 10 teachers at the junior high school level, have had at least 15 semesters of college coursework in science. In many cases, however, that coursework is not in the areas recommended by the science education profession for the subjects they are teaching (Weiss, et al., 1989).

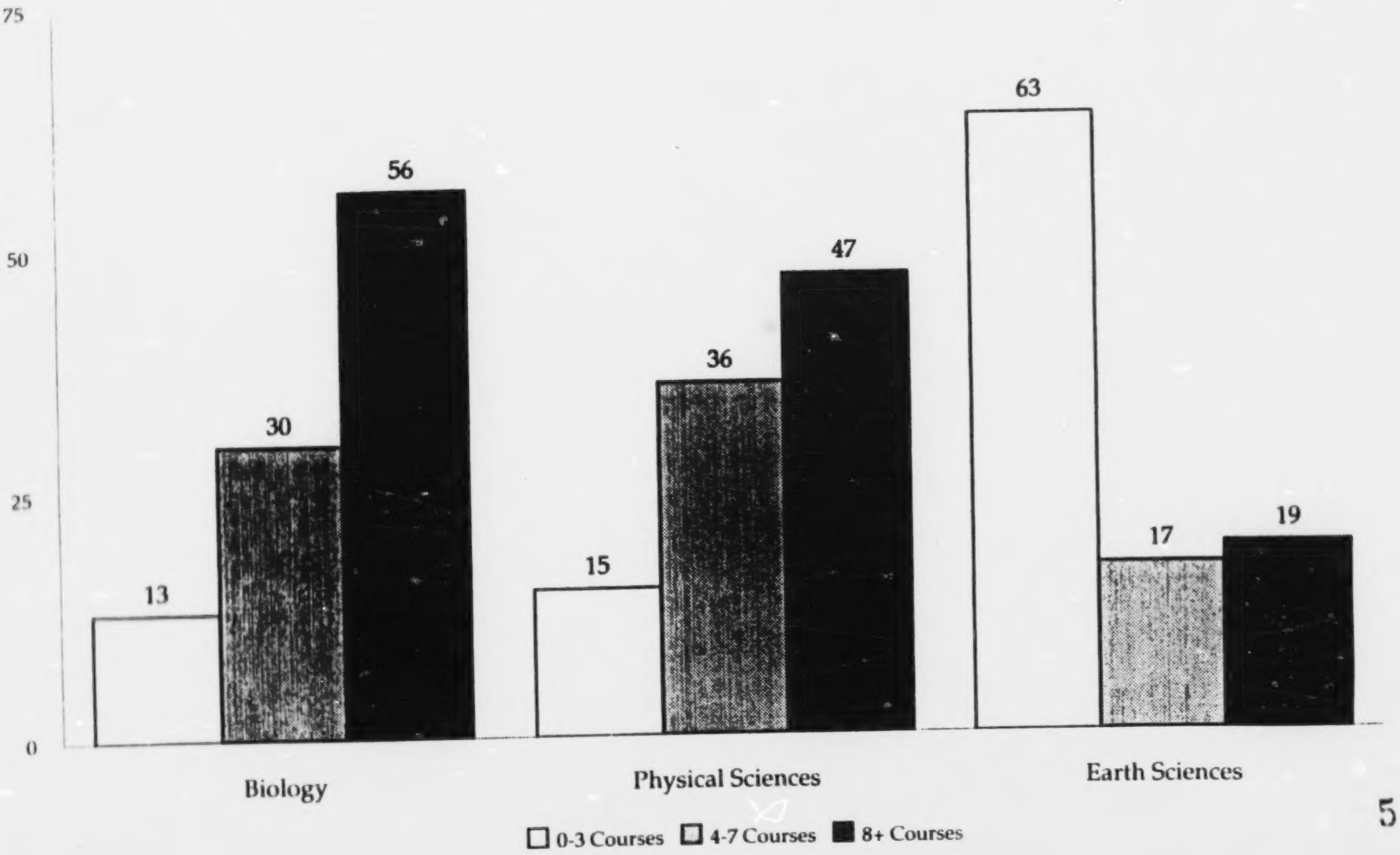
For example, the National Science Teachers Association (1984) has recommended that middle/junior high school science teachers have three courses in each of the major science areas (biological, physical, and earth/space), as well as a course in the methods of teaching science. In 1985-86, fewer than one in four junior high school science teachers met that standard. Most teachers assigned to teach life science and physical science classes had taken a reasonable amount of coursework in those areas (see Figure 2-3). The same cannot be said for earth science: 22 percent of earth science teachers had *no* college coursework in the earth or space sciences, and another 41 percent had three or fewer earth or space science courses — hardly sufficient preparation for teaching a curriculum that typically includes topics in geology, astronomy, meteorology, and oceanography (Weiss, et al., 1989).

Relatively few high school science teachers met the NSTA's recommended standards in biology, chemistry, or physics. In biology, for example, the NSTA recommends that teachers have 32 credit hours, including coursework in each of eight specific areas (zoology, botany, physiology, genetics, ecology, microbiology, cell biology, and evolution); 16 hours of supporting coursework in chemistry, physics, earth or space science, and mathematics; and a course in science teaching methods. In the analysis of the 1985-86 survey data, a fully qualified biology teacher was defined as one with at least eight biology courses, including coursework in each of the specific biology areas listed (with the exception of evolution, since it is an integral part of each of the biology areas and is typically not offered as a separate course) (Weiss, et al., 1989).

Only 29 percent of the nation's biology teachers met or exceeded those standards; many others were lacking only one or two of the specific courses recommended by the NSTA. Similarly, 31 percent of chemistry teachers met the NSTA's recommended standards (32 hours of study in organic chemistry, inorganic chemistry, analytical chemistry, physical chemistry, and biochemistry) (Weiss, et al., 1989). However, only 12 percent of physics teachers met the NSTA's recommended standards for 32 semester hours in physics, including coursework in

Figure 2-3

Percentage of Junior High School Science Teachers Who Have Taken Courses in Their Field



Source: 1985-86 National Survey of Science and Mathematics Education

(c) Horizon Research, Inc. 8/89

classical mechanics, electricity and magnetism, heat and thermodynamics, waves, optics, atomic and nuclear physics, radiation and radioactivity, and relativity and quantum mechanics (Weiss, et al., 1989).

While relatively few high school science teachers met the NSTA's standards in terms of specific courses, most had a substantial amount of coursework in their discipline — especially biology teachers. As shown in Figure 2-4, about four out of five biology classes, but only three in four chemistry classes and two in three physics classes, were taught by teachers with six or more courses in that discipline. Sizeable proportions of physics and chemistry classes were taught by teachers who lacked in-depth preparation in that discipline (Weiss, et al., 1989).

Mathematics Teachers

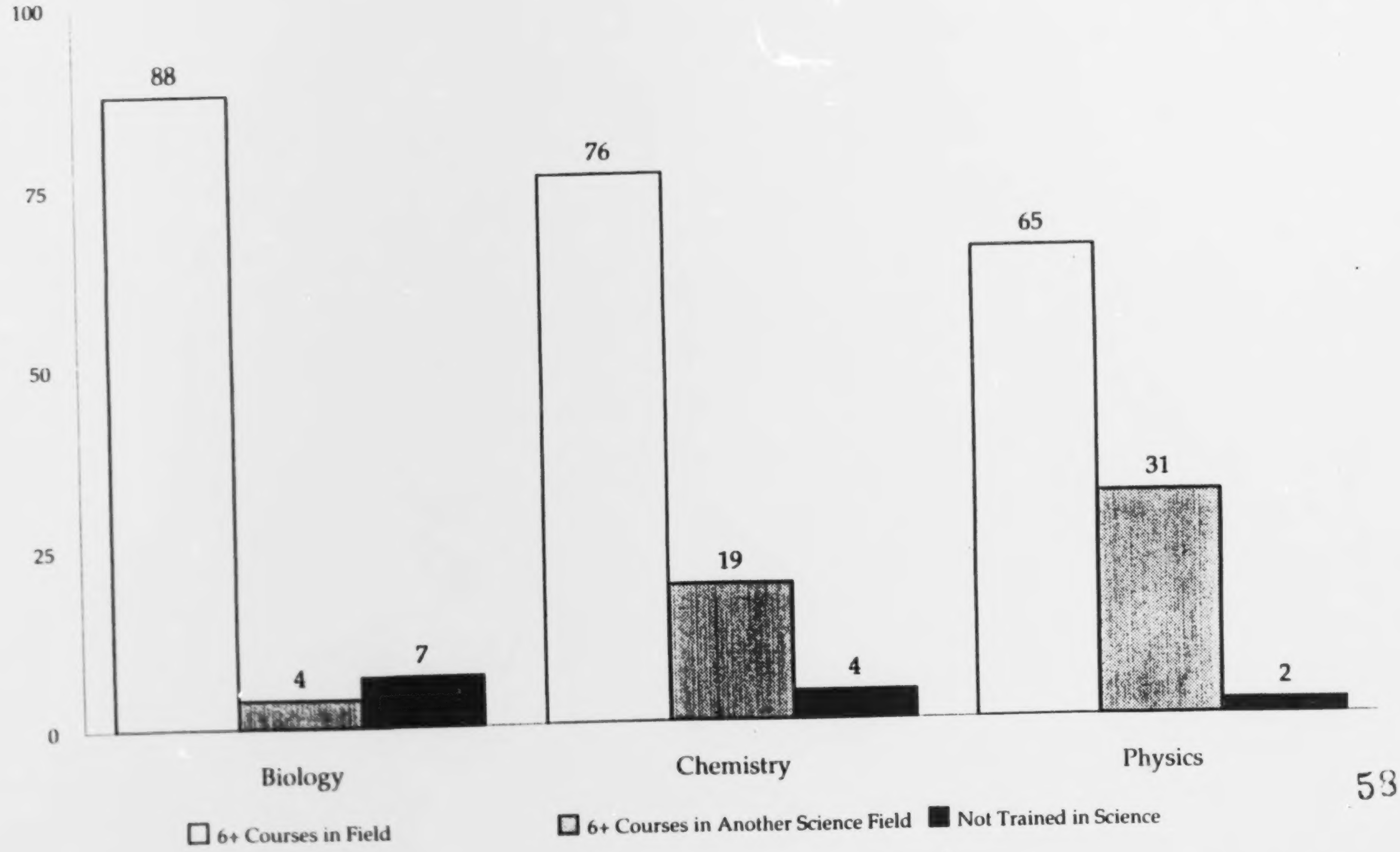
Because secondary school mathematics teachers are expected to teach several different mathematics areas (algebra, geometry, etc.) it is important that they have a broad background in mathematics. The 1985-86 national survey included questions about teacher course background in a total of 11 mathematics areas. Based on data provided by teachers, 70 percent of mathematics teachers in grades 10-12 and 46 percent of those in grades 7-9 had completed coursework in at least 7 of the 11 areas. If an "out-of-field" teacher is defined as one who has had coursework in fewer than 4 of the 11 mathematics areas, then 30 percent of grades 7-9 mathematics classes, but only 7 percent of grades 10-12 classes, were taught by "out-of-field" teachers (Weiss, et al., 1989).

In many cases, however, the courses teachers have taken are not the ones recommended by the mathematics education profession. Assuming that prospective mathematics teachers have had at least three years of high school mathematics, the National Council of Teachers of Mathematics (1985) recommends that junior high school mathematics teachers have college coursework in five areas of mathematics (calculus, geometry, abstract algebra/number theory, applications of mathematics, and probability and statistics), as well as methods of teaching mathematics, and computer science using a high-level programming language.

At the junior high school level, only 10 percent of mathematics teachers fully met the NCTM standards; another 4 percent had completed the necessary courses in mathematics and methods of teaching mathematics courses but had not had a course in computer programming.

Figure 2-4

Percentage of High School Science Teachers Who Have Taken Courses in Their Field



Source: 1985-86 National Survey of Science and Mathematics Education

(c) Horizon Research, Inc. 8/89

It is particularly distressing to note that 22 percent of mathematics teachers in grades 7-9 had taken coursework in no more than one of the five mathematics areas recommended by the NCTM (Weiss, et al., 1989).

At the high school level, the NCTM recommends an extensive mathematics background (including three courses in calculus and coursework in linear algebra, abstract algebra, college geometry, probability and statistics, application of mathematics, and "other upper division mathematics"), as well as coursework in computer programming and in methods of teaching mathematics. While only 12 percent of mathematics teachers in grades 10-12 fully met the NCTM standards, a total of 54 percent had completed at least 8 of the 10 NCTM-recommended mathematics courses (Weiss, et al., 1989).

2.2.4 Continuing Education

Even teachers who are initially well prepared need opportunities to keep up with changes in their fields. In addition, less well prepared teachers need in-service education to help remedy inadequacies in their pre-service preparation. Results of the 1985-86 National Survey of Science and Mathematics Education, however, indicate that many teachers are not being reached by in-service education. As can be seen in Table 2-1, 50 percent of elementary school teachers had received *no* in-service education related to science teaching in the previous year; another 22 percent had received less than 6 hours of in-service training. While in-service education in secondary school science and in both elementary and secondary school mathematics was somewhat more common, more than half of these teachers had participated in only minimal (less than 6 hours) in-service work. Very few elementary and secondary school science and mathematics teachers (ranging from 3 percent to 12 depending on subject and grade range) had spent 35 hours or more on science or mathematics in-service activities (Weiss et al., 1989).[2]

Teachers in the 1985-86 national survey were also asked when they had last taken a course for college credit in the selected subject area (science or mathematics). These results are shown in Table 2-2. It is encouraging to note that more than half of all secondary school science and mathematics teachers had taken courses in their subject area in the previous 5 years.

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[2] *Given the increase in federal support for science and mathematics in-service education since the mid 1980s, especially in the Department of Education's Title II/Eisenhower Program and in the NSF's Teacher Enhancement Program, one would expect that much larger percentages of teachers are now participating in these activities. The most recent data available, however, indicate that only 11 percent of eighth grade science teachers and 14 percent of eighth grade mathematics teachers had spent more than 35 hours on in-service education in these subjects during the previous year (Mullis, Dossey, Owen, & Phillips, 1991; Jones, Mullis, Raizen, Weiss, & Weston, 1992).*

Table 2-1

Total Amount of Time Spent on Inservice Education in Subject in Last 12 Months 1985-86

	Percentage of teachers					
	None	Less than 6 hours	6-15 hours	16-35 hours	More than 35 hours	Unknown
Mathematics						
K-6	41	29	15	5	3	7
7-9	31	25	11	11	8	4
10-12	35	18	13	13	10	3
Science						
K-6	50	22	13	4	3	8
7-9	30	22	22	12	10	4
10-12	27	23	25	12	12	1

Source: Weiss, I. R., Nelson, B. H., Boyd, S. E., & Hudson, S. B. (1989). *Science and mathematics education briefing book: Vol. I.* Chapel Hill, NC: Horizon Research, Inc.

Table 2-2

Most Recent Coursework in Subject for College Credit 1985-86

	Percentage of Teachers					
	Science			Mathematics		
	K-6	7-9	10-12	K-6	7-9	10-12
Last 5 years	28	61	57	37	48	53
5-9 years ago	22	15	18	18	17	19
10-15 years ago	19	14	15	19	19	12
More than 15 years ago	31	10	10	26	16	16

Source: Nelson, B. H., Weiss, I. R., & Capper, J. (1990). *Science and mathematics education briefing book: Vol. II.* Chapel Hill, NC: Horizon Research, Inc.

On the other end of the scale, however, roughly 30 percent of secondary school science and mathematics teachers, and almost half of those at the elementary school level, had not had a course in the selected subject in the previous 10 years (Weiss, et al., 1989).

Finally, in an attempt to learn about teacher preferences with regard to continuing education, teachers were asked the following question: "Suppose you wanted to find out about the research related to a topic (e.g., mathematics anxiety or sex differences in learning). How likely would you be to use each of the following sources of information?" Of the 13 sources listed, those most frequently cited as "very likely" to be used included journals, in-service programs, other teachers, college courses, research reviews, and meetings of professional organizations (see Table 2-3). Elementary school teachers were more likely than secondary school teachers to cite principals and local specialists on a subject as likely sources of information, and science teachers were more likely than mathematics teachers to indicate they would consult television and newspapers and magazines. Relatively few science and mathematics teachers cited publishers and sales representatives, state department personnel, or consultants as likely sources of information (Weiss, 1987).

2.3 A Profile of Science and Mathematics Instruction

Science and mathematics teaching rarely approaches the standards of excellence established by the profession. Lectures and textbooks continue to play a central role in instruction, with hands-on experience and small-group work much less frequent. Based on survey data provided by teachers, with the exception of the primary grades in science, more than 90 percent of elementary, middle, and high school science and mathematics classes use textbooks (Weiss, 1987). In addition, more than half of the eighth grade science teachers in a recent National Assessment survey indicated that they rely primarily on textbooks to determine what they teach (Jones, et al., 1992). Instruction typically emphasizes rules, procedures, facts, terminology, and right answers. For example, Cohen and Ball characterized elementary school mathematics instruction as follows:

> *Teachers stand at the board, show students how to do a particular procedure or type of problem, and assign practice exercises. Students then work quietly on these, asking the teacher for help if they get stuck. When students are done, the teacher checks their answers, marks the ones that are wrong, sometimes goes over the steps once again, and then students fix their incorrect answers . . . . Students' contributions are limited to doing as they are told, memorizing procedures, learning*

Table 2-3

Science/Mathematics Teacher Sources of Information
1985-86

	Percentage of teachers "very likely" to use each source					
	Science			Mathematics		
	K-6	7-9	10-12	K-6	7-9	10-12
In-service programs	53	41	33	46	37	36
Journals	34	52	54	36	40	41
College courses	27	46	41	34	33	32
Research Reviews	27	39	40	32	32	34
Newspapers/magazines	45	39	39	28	24	20
Other teachers	44	37	43	41	37	40
Local subject specialists/coordinators	37	32	26	36	30	25
Television/radio	35	22	26	15	14	9
Meetings of professional organizations	14	20	25	17	27	29
Consultants	23	16	13	21	16	13
Principals	20	9	7	22	15	9
State Department personnel	9	10	8	8	9	8
Publishers and sales representatives	8	6	4	7	5	3

Source: Weiss, I. R. (1987). *Report of the 1985-86 national survey of science and mathematics education*. (RTI No. 2938/00-FR). Research Triangle Park, NC: Research Triangle Institute.

> *"facts," and giving brief, unexplicated answers to highly focused teacher questions*. (1990)

While textbook selection is typically a districtwide decision (from the state-approved list in textbook adoption states) rather than the choice of individual teachers, teachers have considerable latitude in the instructional activities they use. For example, according to the 1990 National Assessment of Educational Progress, the majority of eighth grade science and mathematics teachers indicated they have a great deal of freedom in making decisions about the way they teach (Mullis, et al., 1991; Jones, et al., 1992). Data on these decisions — what teachers say they are trying to accomplish and how they go about it — are presented in the following sections, followed by examples of instruction drawn from classroom observations.

2.3.1 Objectives of Science and Mathematics Instruction

In 1985-86, elementary and secondary school science and mathematics teachers provided information about the extent of emphasis of each of a number of instructional objectives in a randomly selected class. These results are shown in Tables 2-4 and 2-5. According to science teachers, by far the most heavily emphasized objective at the secondary school level was having students learn basic science concepts, followed by having students develop a systematic approach to solving problems.[3] At the elementary level, learning basic science concepts and having students become aware of the importance of science in daily life received about the same emphasis. Far fewer teachers at each grade level emphasized having students become interested in science or learn to communicate science ideas (Weiss, 1987).

The most recent data available on objectives of science instruction are from the 1990 National Assessment of Educational Progress (NAEP). According to data provided by eighth grade teachers, understanding key science concepts remains the most heavily emphasized objective. Unfortunately, having students learn science facts and terminology is also a major goal of many classes at that level. Based on teacher reports, 46 percent of eighth graders attend science classes where facts and terminology receive heavy emphasis; another 51 percent are in classes where facts are given "moderate" emphasis (Jones, et al., 1992). These results are in direct opposition to the recommendations of many in the science education community who advocate a marked de-emphasis on facts and terminology (American Association for the Advancement of Science, 1989; Aldridge, 1989; The National Center for Improving Science Education, 1991).

The two most heavily emphasized objectives in 1985-86 mathematics classes were to have students learn mathematical facts and principles and to have them develop a systematic approach to problem solving. Developing inquiry skills and learning to communicate mathematics ideas were much less likely to be emphasized. Several objectives were much more likely to be stressed in the lower grades than in the higher grades, including emphasis on performing computations, having students become interested in mathematics, and having them learn about the importance of mathematics to daily pursuits (Weiss, 1987).

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[3] *Again the reader is cautioned to keep in mind the limitation of self-reported data. It is not at all clear how teachers interpreted the phrase "basic science concepts." In fact, other evidence indicates that while the concepts being considered are often important, the way they are taught frequently emphasizes factual knowledge rather than conceptual understanding (Boyd & Crawford, 1989; Aldridge, 1989).*

Table 2-4

Objectives of Science Instruction by Grade Range 1985-86

	Percentage of science classes with heavy emphasis*		
Objective	K-6	7-9	10-12
Learn basic science concepts	67	85	86
Become aware of the importance of science in daily life	68	68	59
Develop a systematic approach to solving problems	48	63	67
Develop inquiry skills	55	62	57
Prepare for further study in science	42	52	56
Become interested in science	54	51	45
Learn to effectively communicate ideas in science	45	46	47
Develop awareness of safety issues in lab	23	52	54
Develop skills in lab techniques	15	45	55
Learn about applications of science in technology	27	40	39
Learn about the career relevance of science	22	30	31
Learn about the history of science	9	12	12

* Teachers were given a 6-point scale for each objective, with 1 labeled "none," 2 "minimal emphasis," 4 "moderate emphasis," and 6 "very heavy emphasis." These numbers represent the total circling either 5 or 6.

Source: Weiss, I. R. (1987). *Report of the 1985-86 national survey of science and mathematics education*. (RTI No. 2938/00-FR). Research Triangle Park, NC: Research Triangle Institute.

Recent NAEP data indicate that roughly nine out of 10 fourth graders attend classes where learning facts and concepts receive heavy emphasis; by the eighth grade, this proportion has dropped to fewer than six out of 10. Similarly, while 85 percent of fourth graders receive heavy emphasis on learning to solve routine problems, by the eighth grade the figure has dropped to 68 percent. It is disconcerting to note that reasoning or communication skills are heavily emphasized with only a relatively few students at either the fourth or eighth grade level (Mullis, et al., 1991).

Table 2-5

Objectives of Mathematics Instruction by Grade Range
1985-86

	Percentage of mathematics classes with heavy emphasis*		
Objective	K-6	7-9	10-12
Know mathematical facts, principles, algorithms, or procedures	81	80	71
Develop a systematic approach to solving problems	72	76	75
Prepare for further study in mathematics	60	67	61
Perform computations with speed and accuracy	72	59	41
Become aware of the importance of mathematics in daily life	71	61	41
Develop inquiry skills	51	50	51
Learn to effectively communicate ideas in mathematics	49	54	42
Become interested in mathematics	60	40	31
Learn about the applications of mathematics in technology	20	27	31
Learn about the career relevance of mathematics	15	28	29
Learn about the history of mathematics	4	5	5

Teachers were given a 6-point scale for each objective, with 1 labeled "none," 2 "minimal emphasis," 4 "moderate emphasis," and 6 "very heavy emphasis." These numbers represent the total circling either 5 or 6.

Source: Weiss, I. R. (1987). *Report of the 1985-86 national survey of science and mathematics education*. (RTI No. 2938/00-FR). Research Triangle Park, NC: Research Triangle Institute.

2.3.2 Survey Data on Class Activities

Science Instruction

Elementary and secondary school science and mathematics teachers described their most recent lesson in a randomly selected class by indicating which of a number of class activities took place during that lesson. As can be seen in Table 2-6, most science lessons in 1985-86 included lecture and discussion. Use of hands-on activities was more common in elementary than in secondary school science classes. Moreover, there has been a decline in the use of hands-on science instruction since a similar survey in 1977 (Weiss, 1987).

Table 2-6

Science Classroom Activities Reported by Teachers for Most Recent Lesson (1985-86)

	Percentage of classes		
	K-6	7-9	10-12
Lecture	74	83	84
Discussion	87	82	80
Demonstrations	52	42	44
Hands-on or laboratory materials	51	43	39
Use of computers	2	5	5
Working in small groups	33	35	36
Doing seatwork from textbook	31	45	35
Completing supplemental worksheets	38	44	37
Assigning homework	28	54	52

Source: Weiss, I. R. (1987). *Report of the 1985-86 national survey of science and mathematics education*. (RTI No. 2938/00-FR). Research Triangle Park, NC: Research Triangle Institute.

Based on data supplied by eighth grade teachers as part of the 1990 NAEP, lecture and discussion continue to dominate science instruction: 84 percent of the "most recent" lessons included lecture and 91 percent included discussion, compared with 50 percent where the students were using hands-on or laboratory materials (Jones, et al., 1992).

Similarly, data collected from 4th, 8th, and 12th grade students in the 1990 NAEP Science Assessment indicate that textbooks play a much greater role in science instruction than do hands-on and other activities. As can be seen in Table 2-7, half or more of the students at each grade level indicated they read the textbook in science class at least several times a week; only about 20 percent said they did science experiments that often (Jones, et al., 1992).

Mathematics Instruction

As shown in Table 2-8, the 1985-86 National Survey of Science and Mathematics Education found that most mathematics lessons included lecture, discussion, and seatwork assigned from the textbook. While one in four high school mathematics lessons involved calculator use, fewer than one in 10 elementary or middle/junior high school lessons included use of calculators. In contrast, half of all elementary school mathematics lessons involved

Table 2-7

Students' Reports of Science Classroom Activities (1990)

	Almost everyday	Several times a week	About once a week	Less than once a week	Never
Read science textbooks					
Grade 4	34	20	16	11	20
Grade 8	32	28	19	11	10
Grade 12	23	24	17	12	25
Discuss science news events					
Grade 4	13	14	21	18	34
Grade 8	16	18	26	21	20
Grade 12	9	16	24	24	27
Work on science problems with other students					
Grade 4	12	14	21	20	33
Grade 8	20	21	20	20	19
Grade 12	20	25	19	12	25
Give oral/written science report					
Grade 4	6	6	13	27	48
Grade 8	2	4	8	38	49
Grade 12	2	3	9	34	53
Do science experiments					
Grade 4	10	10	22	33	25
Grade 8	9	11	21	38	21
Grade 12	6	16	29	24	26

Source: Jones, L. R., Mullis, I. V., Raizen, S. A., Weiss, I. R., & Weston, E. A. (1992). *The 1990 science report card.* U.S. Department of Education, National Center for Education Statistics (NCES No. 92-064). Washington, D.C.: National Center for Education Statistics.

manipulative materials, compared with only about one in six secondary school mathematics lessons (Weiss, 1987).

Based on information collected from fourth, eighth, and twelfth grade students as part of the 1990 NAEP, textbooks and worksheets continue to play a predominant role in mathematics instruction (see Table 2-9). For example, about nine in 10 8th graders reported that they do mathematics problems from their textbooks at least several times a week, 73 percent on a daily basis. Similarly, 58 percent of 4th graders, 39 percent of 8th graders, and 30 percent of 12th graders reported doing mathematics problems from worksheets at least several times a week (Mullis, et al., 1991).

Table 2-8

Mathematics Classroom Activities Reported by Teachers
for Most Recent Lesson
1985-86

	Percentage of classes		
	K-6	7-9	10-12
Lecture	73	89	89
Discussion	85	90	86
Use of calculators	2	9	26
Use of computers	7	6	10
Hands-on or manipulative materials	50	20	12
Doing seatwork from textbook	76	76	66
Completing supplemental worksheets	49	34	26
Assigning homework	39	75	75

Source: Weiss, I. R. (1987). *Report of the 1985-86 national survey of science and mathematics education*. (RTI No. 2938/00-FR). Research Triangle Park, NC: Research Triangle Institute.

Other types of activities, including those advocated by the National Council of Teachers of Mathematics in their recently published *Curriculum and Evaluation Standards for School Mathematics* (1989) and *Professional Standards for Teaching Mathematics* (1991), are not nearly as prevalent. For example, only about one in five students at each of the three grade levels reported working in small groups in mathematics classes at least several times a week; roughly two in five said they *never* worked in small groups.

Only 24 percent of 4th graders and 17 percent of 8th and 12th graders reported working with "objects like rulers, counting blocks, or geometric shapes" at least several times a week. On the other hand, about three out of 10 4th graders and four out of 10 8th and 12th graders reported *never* working with manipulatives in mathematics class (Mullis, et al., 1991).

Table 2-9

Students' Reports of Mathematics Classroom Activities
1990

	Percentage of students				
	Almost everyday	Several times a week	About once a week	Less than once a week	Never
Problems from textbooks					
Grade 4	59	18	9	7	7
Grade 8	73	15	5	4	4
Grade 12	81	11	3	2	3
Problems from worksheets					
Grade 4	33	25	22	15	6
Grade 8	18	21	24	24	13
Grade 12	11	19	23	29	19
Work in small groups					
Grade 4	12	7	14	23	44
Grade 8	8	7	13	27	45
Grade 12	10	10	14	26	41
Work with manipulatives					
Grade 4	12	12	19	27	30
Grade 8	6	11	14	31	39
Grade 12	7	10	10	33	39

Source: Mullis, I. V. S., Dossey, J. A., Owen, E. H., & Phillips, G. W. (1991). *The STATE of mathematics achievement: NAEP's 1990 assessment of the nation and the trial assessment of the states.* U.S. Department of Education, National Center for Education Statistics (NCES No. 21-ST-04). Washington, D.C.: National Center for Education Statistics.

Equality in Education

Recent research has documented considerable inequities in curriculum and instruction in the United States. For example, schools with large proportions of minority and economically disadvantaged students are less likely to offer advanced courses. Oakes, Ormseth, Bell, and Camp (1990) found that only 50 percent of schools with 90 percent or more minority students offer calculus, compared with 80 percent of predominantly white schools. Similarly, studies of elementary schools have found that disadvantaged students tend to receive instruction in computation skills while their more affluent peers learn more complex problem-solving skills (Consortium for Policy Research in Education, 1991).

Grouping students for instruction by their level of ability often results in educational inequities. Because many economically disadvantaged students do not have access to the rich educational resources of middle and upper class homes, they may start school at an educational disadvantage. Perceived as lacking in intellectual ability, they are assigned to low level classes where they are not exposed to the conceptually rigorous curriculum and instruction necessary for continued study in science and mathematics (Mullis, et al., 1991).

Similarly, differential expectations for males and females create educational inequities in science and mathematics. Teachers interact more with male than with female students, calling on them more often, especially when higher-order cognitive questions are involved. In many cases, the behavior that is considered evidence of "a questioning mind" in males is considered "argumentative" in females. Similarly, when teachers are asked to nominate students for special programs, they will nominate males of average ability ahead of gifted females (Kahle & Matyas, 1987).

2.3.3 Observations of Science and Mathematics Classes

Recent studies have shown that teachers, like other learners, construct their own meaning based on prior experience and understandings. For example, researchers reporting on a series of case studies of elementary school mathematics teachers discussed how a number of teachers misinterpreted the recommendation that concrete materials be used to give students access to varied representations of mathematical ideas:

> Several teachers were delighted with the idea; they avidly embraced concrete materials, and used them extensively. In a sense they had implemented the policy. But these teachers' use of the new materials was filtered through their established practice: Some of these teachers offered students no opportunities to figure out what sense they made of the new materials; they used the manipulatives to capture and rivet students' attention on memorizing the traditional rules and procedures. Rather than treating the materials as opportunities to help students construct and articulate their understanding of mathematics, these teachers treated the materials as another didactic agent of direct instruction, presenting traditional menus of mathematical content. Again, the new mathematics instruction was filtered through an older and much more traditional mathematical and pedagogical structure (Cohen & Ball, 1990).

Similarly, observations of secondary school classes indicate that many teachers have not embraced current thinking in mathematics and science education. As a follow-up to the 1985-86 National Survey of Science and Mathematics Education, researchers visited 15 secondary schools across the United States (Boyd & Crawford, 1989). Researchers from the Wisconsin Center for

Education Research also conducted site visits to secondary schools involved in the Urban Mathematics Collaborative Project (Popkewitz & Mýrdal, 1991).

Observations of science and mathematics classes in these schools yielded numerous examples of textbook-dominated instruction, with emphasis on memorizing terminology and solving routine problems. Often laboratory activities seemed designed to have students confirm what they had already been told, with little of the excitement characteristic of the inquiry process. Even when teachers clearly knew about the applications of the science and mathematics concepts in "real life," they paid little attention to them, typically attending to them briefly only in response to student questions, then returning quickly to the prescribed course of study. For example:

> In a "lower level" biology class, a teacher labels the parts of the digestive system on an overhead transparency. She tells the students the function of each part as she goes. A girl in the back of the room is putting on make-up. Two students are throwing paper at each other. Most of the students sit quietly. When the teacher gets to the appendix, a student exclaims, *"That little thing causes all that pain!"* The teacher pauses briefly from labeling the parts to tell the class about appendectomies. The students listen attentively. Then she goes back to the overhead projector, saying, *"I want you to have the parts memorized by Tuesday,"* and proceeds with labeling the parts. Several students go back to chatting among themselves (Boyd & Crawford, 1989).
>
> In an Algebra II class, the lesson is on sines and cosines. The teacher defines terms and formulas and writes them on the board. He says things like, *"You need to know the angles, memorize them; look at the table in your book"* and *"Lock these definitions in your mind."* When he thinks the class has had long enough to copy what he has written on the board, he says, *"Let's get rid of this garbage and look at what you need to memorize — put this in your notes."* In the last 15-20 minutes of class, the students are to work on homework problems; some do, others socialize (Boyd & Crawford, 1989).
>
> The teacher describes his Algebra I class sessions as having five phases: bellwork assignment, bellwork check, homework check, homework lesson, homework assignment. He divides up the 40 minutes into approximately 8 minutes for each phase. As soon as the students are settled, he begins to cover the math problems at a rapid pace, giving one the impression that there is much content to be covered and that the class has been behind schedule for some time. Some students appear to be only partially engaged in the lesson, talking to one another, doodling. A few students seem to be listening carefully to what the teacher is saying and following his instructions. From time to time, these students

> will ask him to clarify a point with an example or to repeat what he has said (Bruckerhoff, 1991).
>
> A biology teacher says she doesn't do many laboratories; she just doesn't have the equipment. In her advanced placement biology class, she draws a cross section of a muscle on the board and lists terms that the students need to memorize for the quiz tomorrow. She tells them what it would look like under a microscope. The students want to know, *"Will we have to draw it? Will we have to know this term?"* The intercom interrupts the class three times during the period. Several students sit at the very back of the room with their chairs tilted back against the wall (Boyd & Crawford, 1989).

Observations of classrooms in these schools also provided evidence of teaching practices that are quite consistent with recommendations of the science and mathematics education community: teachers who are reducing the amount of content coverage so students have a better opportunity to truly understand what they are being taught; allowing students the opportunity to have direct experience with phenomena rather than learning about them only through the written and spoken word; exploring applications of science and mathematics concepts in the "real world;" and generally engaging students as active partners in the learning process.

> On the board in an advanced algebra class is a quote from Plato: "Let no one destitute of geometry enter my door." The teacher has laryngitis today and jokes with the students about her condition. Today's lesson is on adding complex algebraic fractions. The teacher relates new problems back to things they've already learned. The students are attentive; they ask questions freely. One student has a difficult time with a problem the teacher gives him. Other students volunteer to answer the question, but she works with him until he gets it, saying, *"I'm not going to give up on John."* When he gets it, she praises him enthusiastically.
>
> In a 10th grade geology class, the teacher sits on his desk as he talks with the students. There is no lecture here; it is a dialogue between students and teacher. The class goes "off subject" for much of the period because the students ask many questions on environmental issues that relate to today's lesson: siltation. They talk about a nearby river where they used to swim that is now choked with algae; they remember when the bathrooms in their school had to be temporarily closed because the outdated plumbing resulted in inadequate sewage disposal. The conversation moves on to a recent major oil spill in Alaska; the students use words like "stupid" and "ridiculous" to express their concern and anger over the incident.

> A banner reads: "Math is Fine in 1989." Before class, the teacher chats with several students. There are 23 students in this class, mostly Hispanic and black. The students are studying geometric transformations. The teacher explains later that there is only a small amount of geometry in her textbook, so she has added more (Boyd & Crawford, 1989).

Sometimes, though, even teachers who have mastered both the content and the methods of teaching it can't overcome the limitations placed on them by a curriculum that is geared more to "coverage" than to understanding (see sidebar).

2.3.4 Obstacles to Effective Science and Mathematics Teaching

While the teacher is the key to much of what goes on in science and mathematics classrooms, a number of external influences can also affect the quality of instruction. Accordingly, teachers in the 1985-86 National Survey of Science and Mathematics Education were given a list of "factors" that might affect science and mathematics instruction and asked to indicate which, if any, cause serious problems in their school. Resource problems such as insufficient funds for purchasing equipment and supplies, lack of materials for individualizing instruction, and inadequate access to computers were most often cited as serious problems in both science and mathematics instruction. Observations of classes and interviews with teachers in the 1989 follow-up study provided further insights into the problematic working conditions of many science and mathematics teachers (Weiss, 1987; Boyd & Crawford, 1989; Weiss & Boyd, 1990).

Teaching is considered a "profession," but the working conditions most teachers face are not in keeping with professional standards. Rarely do schools provide teachers with office space and telephones; easy access to FAX machines, modems, or secretarial support; or sufficient time in the workday to think, plan, or collaborate with their colleagues.

Moreover, many teachers noted that the equipment they work with in their classes is mostly left over from the early 1960s. One teacher indicated that the only money for equipment and supplies in his classes comes from a five-dollar student laboratory fee which only about half of the students actually pay. As a result, he has to bring a lot from home — household chemicals, baking powder, sugar. Many other teachers mentioned buying supplies for science activities from personal funds; while there are no data available on the actual numbers of teachers using their own money in this way, nor on the amount spent, the practice seems quite common (Boyd & Crawford, 1989).

Other teachers spoke about coming into the profession prepared to teach their subject area and being confronted with the realities of classroom teaching. Said one:

> *"I discovered that not everybody wanted to learn and that was kind of a shock. It turned out to be more of 'Johnny quit throwing spitwads' than it was trying to teach them anything"* (Boyd & Crawford, 1989).

In synthesizing the results on a number of case studies on mathematics teachers, researchers noted that "teaching time is often sacrificed to administrative work: selling notebooks and pencils, collecting money for tickets to various school functions, maintaining attendance records, compiling progress reports, seeing that students get to special help classes, and counseling sessions" (Popkewitz & Mýrdal, 1991). In addition, many teachers believe that mandated curriculum guidelines, performance standards, and other trends toward accountability threaten their ability to teach.

High School Chemistry: Too Much, Too Quickly

Ms. Woodward, a pleasant, energetic woman in her late 40s, clearly knows her subject. Students ask questions freely as she conducts a series of chemistry demonstrations. Ms. Woodward draws examples from previous work in the class and with real-life analogies to help them understand. (All of the students in the school were scheduled for fitness tests that day. To help the class understand the concept of average kinetic energy, Ms. Woodward asked if they had run the mile yet. They had. "Did you all finish at exactly the same time? Could we get an average time for the class? Does that mean everybody ran the same time?")

While these students seem bright and hard-working, and the teacher highly competent in both content and pedagogy, the students have not grasped some very fundamental concepts. They use terms like **endothermic** *and* **exothermic reactions**, *but they clearly do not yet understand the difference between heat and temperature. The problem does not appear to be with either the teacher or the students, but with the curriculum itself. There's simply too much being covered, and too quickly.*

A focus-group interview with several students after class supports this conclusion. The students volunteer that

> "[Ms. Woodward] really knows what she's doing."
>
> "She knows when we're lost [and] she'll try very hard to get it across."
>
> "She tries to relate it to something we know."
>
> "If you ask a question, she tries to explain it another way."
>
> "She's a real nice person; you want to do well."

They talk about really liking labs: "You get to move around, work with each other, learn from each other." But they feel worn out from the pressure of trying to learn so much material: "You're taught so many things in one lesson; you have to concentrate all the time. And if you're absent, forget it." The students are quick to point out that it's not the teacher's fault; they need to get through the material because "there's this test at the end of the year."

These students are intelligent, highly motivated, and diligent. They like and respect their teacher. But the course is convincing them that chemistry is not for them.

(Author's analysis of a chemistry class videotaped by St. John (1991); "Ms. Woodward" is an assigned name.)

A mathematics teacher described the pressure he felt to "cover" the material as follows:

> *"These kids are going to college. They've got to take the SAT. This is the only place they get geometry. If I don't give it to them, they're never going to have it and they're going to do badly on the SAT and that's going to be my fault. So, from the beginning of the book to the end, I worked as hard as I could to get that information into them"* (Muffoleto, 1991).

One teacher said that when she gets detailed guidelines on curriculum and instruction it seems that

> *"everybody assumes I'm a terrible teacher and tells me what I should be doing every single minute of the class period . . . . They impede me. They don't allow me to do the things I know will work. . . . And nobody ever considers what it's like to implement a lot of these things"* (Boyd & Crawford, 1989).

Another teacher noted that she would like to be able to enrich her classes with more than what the state requires but feels pressured to cover the required material. She does not blame the principal for the lack of flexibility; the principal seeks input from teachers, but all too often her hands are tied by district and state regulations.

Most often, teachers directed their anger over the loss of freedom in the classroom toward the "powers that be": central office staff, state-level personnel, and "reformers." Teachers believe that many of these people have been out of the classroom for years and are therefore out of touch with its reality. They note that even teachers who have been away from teaching for only a short time forget what it is like (Boyd & Crawford, 1989).

2.4 Conclusion

By all accounts — from teachers, students, and researchers — science and mathematics instruction is all too often a dull, dry, textbook-dominated routine, lacking the sense of engagement and intellectual excitement that is characteristic of these disciplines. While there are some teachers in the field with wholly inadequate course background preparation, the problem does not appear primarily to be a lack of content knowledge on the part of teachers. Rather, the problem seems to be that teachers hold a vision of science and mathematics instruction that focuses on conveying as much information as possible, on as many topics as possible, in as short a time as possible.

Even those elementary school teachers who have had the science and science methods coursework recommended by professional associations do not feel well prepared to teach science. Neither college science courses nor science methods courses appear to be providing prospective elementary school teachers with the background they need to feel comfortable teaching science to young children. Judging from the content of some popular textbooks for introductory college science courses, it is not surprising that elementary school teachers would find it difficult to translate what they have been taught into terms and examples that young children would find meaningful. Part of the challenge of in-service education is to help teachers learn how to relate science concepts to the needs and interests of their particular students.

While many elementary school teachers perceive themselves to be well prepared to teach mathematics — based both on their course background and on the content of their mathematics classes, it may well be that they feel well prepared to teach arithmetic but not geometry and spatial sense, probability, statistics, or other topics currently recommended for the elementary school grades. In-service education can serve to provide these teachers with an opportunity to both gain an understanding of these content areas and to learn how to engage students in learning these topics.

At the secondary school level, most science and mathematics teachers have had a considerable amount of coursework in their subject area. But exposure to large amounts of coursework seems to be no guarantee that teachers will teach a subject in the ways that research has shown to be most effective for student understanding. Science instruction continues to be dominated by the "textbook-lecture-recitation" methodology, and mathematics by the familiar "chalk and talk" routine. It is axiomatic that teachers should themselves have a good understanding of the subjects they are teaching. It also appears clear that teachers teach as they themselves were taught. If we want teachers to make use of cooperative learning strategies and inquiry-based instruction, we need to give them an opportunity to learn that way themselves, both in their pre-service courses and in in-service offerings as well.

Regardless of the adequacy of their pre-service preparation, teachers will need opportunities for continuing education in order to keep up with advances in their disciplines and in teaching techniques. In-service education is clearly essential. But it is just as clearly only a part of the solution for the problems in science and mathematics education. Improving the knowledge and skills of the nation's science and mathematics teachers will have little impact if these teachers must continue in situations with poor working conditions, inappropriate curricula, and inadequate facilities, equipment, and supplies. The challenge for in-service education goes beyond teacher enhancement to creating a support structure that will enable teachers to translate what they learn into improved learning for students.

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PART TWO: IN-SERVICE EDUCATION IN THE SCIENCES

INTRODUCTION

Jose P. Mestre, Senta A. Raizen, and Richard J. Shavelson

The three chapters that follow treat three areas that are crucial for teacher enhancement in the sciences: cognitive aspects of learning and instruction, approaches to curricular reform, and in-service teacher education models. Various themes recur throughout these three chapters, largely because of the agreement that exists about their importance in the current reform movement in science and mathematics education. In this brief introduction we simply highlight those themes — their full development is contained in the chapters that follow.

Perhaps the single most important theme that stands out throughout these chapters, and throughout this book, is the notion of constructivism. Constructivism is a view of learning in which individuals build and impose sense upon their own knowledge from their own experiences. The construction of meaningful knowledge is a lifelong, time-consuming, arduous mental task that can be facilitated by instruction but is not the direct consequence of instruction; that is, knowledge cannot be absorbed in ready-to-use form through instruction, no matter how clear the instruction may be. The neophyte must construct and make sense from a learned individual's knowledge in his or her own manner. In this sense, knowledge and wisdom are private entities residing within the individual. The constructivist view is not an abstract "theory" that emerged from the halls of academe — it is a synthesis of considerable research into learning, and it is embraced by the reform movement because it can accommodate most of our observations on human learning and problem solving.

From a constructivist perspective, any activity that actively engages the individual in the construction of knowledge is desirable — many recent trends in educational practice reflect the importance of an active involvement in learning. For example, cooperative learning, hands-on activities, and inquiry-based science all engage learners in interacting with their environments. These types of learning activities are situated within concrete contexts where students construct knowledge by direct experience and then abstract from their experiences the underlying concepts, as well as the conditions under which those concepts apply in the related contexts. The teacher's role is to help students in this endeavor by providing the necessary structure and guidance.

Prior knowledge plays a major role in learning within the constructivist model. Learners come to any learning experience with resident knowledge that may or may not be consistent with new experiences and observations. When resident knowledge conflicts with new experiences and observations, learners deal with the dissonance in numerous ways. They may simply deny the dissonance. Or instead they may reinterpret their observations so that the dissonance disappears. They may also make slight, inconsequential modifications to their resident knowledge so that the dissonance is reduced or eliminated — but not so that future observations can be accommodated with (flawed) resident knowledge. Lastly, learners may restructure their resident knowledge so that it can easily accommodate prior as well as new experiences: this option requires the greatest mental effort by the learner. The challenge of schooling is to channel students' efforts into this last option.

Evidence for the constructivist view abounds in our classrooms once we probe students' thinking. Students possess knowledge about the physical or biological world that is incomplete or perhaps fragmented, knowledge that often does not stand up to scientists' views of the world. The finely honed skills of proficient problem solvers derives largely from their highly developed and organized knowledge base; the not-so-elegant problem-solving approaches used by students can be largely attributed to an incomplete, poorly organized knowledge base. These issues are reviewed in the chapters by Mestre and Raizen.

What will become clear to the attentive reader from the chapters that follow is that current educational practices do not reflect the constructivist perspective. If we buy into the notion that constructing knowledge is a time-consuming, effortful process and that learners will be able to retain and use knowledge only if it makes sense to them, we need to ask why science education consists largely of superficially covering large amounts of information with little regard to helping the student structure and make sense out of it. Clearly the information explosion in science has something to do with this. However, we need to curb this trend and focus our efforts on helping students acquire a sound foundation of the overarching ideas permeating the sciences. In view of the clear evidence that students emerge from science courses with little understanding of major scientific concepts, and that much of the information they memorize is forgotten shortly after they finish a course, one would think that the educational establishment would have taken pause long ago. Fortunately the "less is more" philosophy is evident in the various curricular reforms reviewed in Raizen's chapter; national curricular reform projects focus on having students build a solid foundation of major scientific concepts, believing that such a foundation will help students construct subsequent scientific knowledge.

Like students, teachers are also learners and construct knowledge about what they perceive to be effective instruction. In their chapter, Shavelson, et al. refer to this knowledge as a "mental map," containing knowledge about students, curricula, classroom settings, and teaching methods. Mestre refers to it as teachers' "cognition of instruction." The eventual impact that the current reform movement will have hinges perhaps most critically on our ability to cultivate teachers' cognition of instruction. The knowledge that teachers have constructed about effective instruction is largely a function of their own educational experiences. Unfortunately, teachers, like most of us, have gone through an educational experience based on a "transmission" model of instruction rather than a constructivist model. Just like students' having to reconstruct knowledge in the face of dissonance, teachers will have to reconstruct their cognition of instruction if they wish to adopt instructional strategies that are consistent with constructivism.

Shifting instructional practices in science from those based on transmitting voluminous amounts of information to those based on having students construct, organize, and understand the major concepts underlying science will require the involvement and cooperation of various groups. Some of these groups, as identified in Mestre's chapter, include scientists, commercial publishers, and test makers. Change will not come quickly. Perhaps a useful way of envisioning charting a new direction in science education is to envision a large ocean liner making a ninety-degree turn — shortly after the rudder is moved there is little perceptible change in the direction of the ship, but eventually we see signs of a change in course.

3 COGNITIVE ASPECTS OF LEARNING AND TEACHING SCIENCE

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3.1 Introduction

Imagine the following scenario:

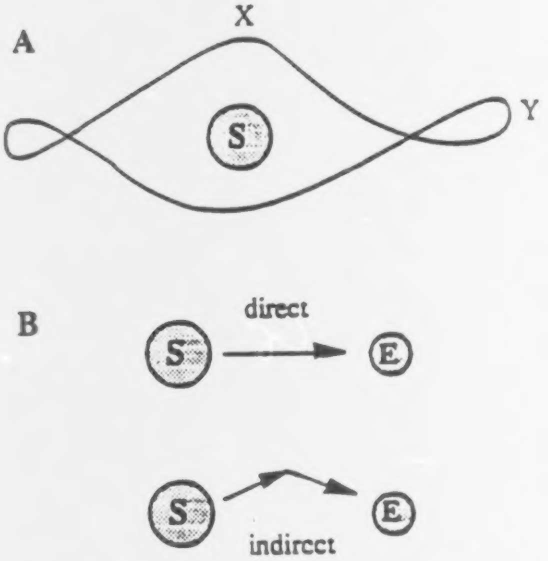
> *Heather, a very bright ninth grader, is asked to explain the mechanisms causing the seasons and the phases of the moon. She has not yet received any formal instruction on these topics in her ninth grade earth science class, although these topics were covered in science lessons from earlier grades. During the course of her explanations, Heather displays some misconceptions. For example, she believes that the earth orbits the sun in a bizarre "curlicue" pattern (see Figure 3-1A), and that the seasons are caused by the proximity of the earth to the sun at different times during the orbit. She explains that when the earth is closest to the sun, at point X in Figure 3-1A, it is winter in the northern hemisphere because the light rays from the sun hitting the earth are "indirect," and that when the earth is at point Y, it is summer because the light rays hitting the northern hemisphere are "direct." She goes on to explain that direct rays are those that originate from the sun and travel in a straight line to the earth and that indirect rays are rays that "bounce off" somewhere in space before reaching earth (see Figure 3-1B). In terms of explaining the phases of the moon, Heather believes that the shadow of the earth on the moon causes the phases.*

This scenario is not fiction — it summarizes events that actually transpired during an interview in a school in Cambridge, Massachusetts, events that are well documented in the educational video *A Private Universe* (Pyramid Film and Video). Heather clearly has formed a mental representation that mixes both erroneous and correct ideas into a muddled package. The notion of direct and indirect light does explain the seasons, although this notion has nothing to do with her belief that the earth travels in a curlicue orbit and gets much closer to the sun during certain times of the year. Similarly, she inappropriately applies the mechanism by which lunar eclipses occur to explain the phases of the moon. Like Heather, the students who enter our science classrooms possess many incorrect notions that they use to explain scientific phenomena. The problem with these incorrect notions is that many of them are resistant to

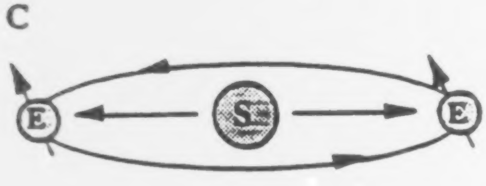
Figure 3-1

Scientific conceptions on astronomy held by a bright ninth grade student:
(A) The earth follows a curlicue orbit around the sun.
(B) Student's representation of direct and indirect sunlight.
(C) Accurate explanation of the cause of the seasons.

Misconceptions held by student upon entering ninth grade



Student is able to overcome some misconceptions following instruction



instruction. Students retain a considerable number of their erroneous beliefs following lessons in which lucid explanations are provided for the phenomena in question. Let us persist with Heather's story and see what happens:

> *Heather receives formal instruction in her earth science class, where explanations are provided on the causes of both the seasons and the phases of the moon. Two weeks following formal instruction, Heather is asked the same questions in another interview. Instruction has helped Heather overcome several of her misconceptions. For example, Heather now knows that it is not the shadow of the earth on the moon that causes the phases of the moon, but the relative positions of the earth, moon, and sun as light rays from the sun strike the moon, reflect off it and hit the earth. Heather has also overcome her misconception about a curlicue path of the earth around the sun (she recalls that she got that notion from a figure she saw in a science textbook). She now explains that the earth follows close to a circular path around the sun. Furthermore, instruction has also changed Heather's view of the seasons' being caused by the proximity of the earth to the sun; she now realizes that the earth is nearly the same distance from the sun during the course of the year. She explains by drawing a diagram that the seasons are caused by the tilt of the earth's axis, which causes "direct" and "indirect" light to fall on the northern and southern hemispheres of the earth (see Figure 3-1C). However, when asked to explain what she means by "direct" and "indirect" light, Heather resorts to her previous beliefs — she shows indirect light as being light that bounces off points in space, like light bouncing off a mirror, before hitting the earth. Even a strong hint from the interviewer — she is shown diagrams of what is meant by direct and indirect sunlight — did not change Heather's mind. She incorporated the hint into her erroneous view by saying that the indirect light from the sun that caused winter in the northern hemisphere was light that bounced off some other point on the earth before reaching the northern hemisphere.*

Heather was unable to overcome some of her misconceptions as a result of instruction. She interpreted the classroom lessons explaining direct and indirect light according to her notions about the path taken by light from the sun (Figure 3-1B). Instruction, therefore, was only partially successful in helping Heather overcome some fundamental scientific misunderstandings. Heather is not unique. In fact, she is in good company. The same video shows interviews of Harvard graduates and Harvard faculty at commencement, all still wearing their caps and gowns, in which they display exactly the same erroneous views about the causes of the seasons and the phases of the moon that Heather displayed prior to receiving formal instruction in the ninth grade. The only difference between Heather and the Harvard graduates was that the Harvard graduates delivered their explanations with much more aplomb.

We might be inclined to interpret this scenario as evidence of the poor science teaching that takes place in American schools, but this interpretation would be not only far too simplistic, but also inaccurate. The science teacher who taught the ninth grade class was well versed in earth science, well liked by her students, and would be judged a very good teacher by any evaluation team that observed her teaching methods. The truth is that scenarios like this are more the norm than the exception in American schools. Students from kindergarten to college taught by teachers who would be judged competent by any reasonable standard are emerging from science courses with a very poor understanding of both scientific concepts and the nature of science in general. This situation mirrors the standing of American students in international science assessments: American students lag behind those from most other industrialized nations in both science and mathematics achievement (International Assessment of Educational Progress, 1992).

It is against this backdrop that the recent educational reform movement in mathematics and science has emerged. The new reform movement is both a top-down and a grass-roots movement. At the top, the reform movement was being fueled by then-President Bush and his Secretary of Education, along with the National Research Council and the National Governors Association. The document that was to serve as the strategy for the educational reform, *America 2000*, is already in place, and one of its goals states that the U.S. will be number one in the world in science and mathematics achievement by the year 2000. Other reforms in science include the Scope, Sequence and Coordination project from the National Science Teachers Association, and Project 2061 (American Association for the Advancement of Science [AAAS], 1989). The grass-roots reform movement is much farther ahead in mathematics education than in science education. Mathematicians and mathematics educators, working with the National Council of Teachers of Mathematics (NCTM), have constructed coherent plans for implementing change in both the mathematics curriculum (National Council of Teachers of Mathematics (NCTM), 1989) and the teaching of mathematics (NCTM, 1991). Although no such documents exist for science education, the National Academy of Sciences is beginning a process by which similar blueprints will be constructed by scientists and science educators.

What will it take for the new reform movement to have the desired impact on student achievement in science? There are some obvious ingredients that have to be present in order for any reform movement to have a measurable impact. These are adequate financial support, the active involvement of scientists and educators, acceptance of the "final products" by science teachers, and educating teachers in the use of these final products, whether they be curricular materials or instructional practices. It was the presence of these ingredients in the reform movements of the fifties and sixties that resulted in the scientific heyday of the sixties and seventies. Unfortunately, due largely to the erroneous assumption that the new materials would sustain themselves without continued revision and in-service teacher training, most of the excellent science materials that emerged from the previous reforms have all but disappeared from use in science classrooms today (Shymansky, Kyle, & Alport, 1983; Swartz, 1991).

There is one thing that sets the current reform movement apart from the post-Sputnik reforms. Today we have available a large (and growing) body of research findings on learning and problem solving in the sciences and mathematics. This body of research, generally termed "cognitive research" — most of which has emerged over the last 15 years — has important ramifications for learning and instruction. The central concern of cognitive research is to understand the mental processes involved in the acquisition of knowledge and in the use of knowledge to solve complex problems. A discussion of the nature of this body of research and its implications for learning and teaching science is the main goal of this chapter.

In this chapter I argue that, in addition to needing the ingredients mentioned above for a successful reform movement, two other factors should loom large in the development of new instructional materials in science and in the design of new instructional strategies. The first is cognitive research findings on teaching, learning, and problem solving. The need to have cognitive research findings guide curriculum development would seem obvious. If we were given the task of developing a faster computer, we would start by studying the newest and best technology available and then investigate how this new technology could be incorporated into making computers achieve faster computing speeds. We would not set about this task by resorting to simplistic approaches such as using thicker wires, or adding more of the same kinds of chips that are currently inside computers, or painting the computer casing in brighter, shinier colors. Yet, the latter is the approach of choice in developing commercial educational materials today. Textbook publishers and textbook writers largely ignore cognitive research findings and continue to clone new textbooks from best-selling editions or "improve" existing textbooks by adding color, changing the type size, or making similar cosmetic changes. Market considerations, more than learning considerations, drive the commercial publishing establishment.

The second factor that should influence curriculum reform in science education is the nature of science as it is practiced by scientists. If students are going to study a subject called "science" in school, then the science that they do should in some way reflect the views and practices of actual scientists. Although the science curricula that emerged from the post-Sputnik reforms reflected, albeit at a rudimentary level, science as practiced by scientists, the science curricula used in most American schools today do not. This and the other issues raised above are revisited in detail in the pages that follow.

So as not to create the wrong impression, I am not offering here "the solution" to the current underachievement of American students in science. Rather, I discuss issues of great importance in the formulation of a solution. Other issues that are equally important in formulating a solution — such as the pre-service and in-service education of teachers, the amount of time spent on science and mathematics by students both in and out of school, the role played by parents in their children's education, students' motivation to learn science and math, and the physical and mental safety of children in our schools — are much too complex to treat together in any single article, chapter, or book.

I begin by providing an overview of cognitive research findings on learning and problem solving in science and discuss the implications of this body of research for science instruction. I then examine how science is actually taught in our schools and argue that current instructional practices reflect neither our best understanding of learning and instruction, nor science as it is practiced by scientists. I then discuss possible reforms to bring about closer alignment between instructional practices and both current views of learning and scientists' views of science. I conclude with suggestions on the possible involvement of scientists, cognitive researchers, teachers, school administrators, parents, and government officials in the current educational reform movement.

3.2 Research on Learning and Problem Solving in Science

In this section, three interrelated topics are discussed. First I present a view of learning, called *constructivism*, which is widely held today because of its usefulness in accommodating a wide range of observations on human learning and problem-solving behavior. I then discuss the role played by the knowledge that students already possess in learning scientific concepts, and its relationship to constructivism. I conclude the section with a characterization of both unskilled and skilled problem-solving behavior; the contrasts between skilled and unskilled problem solvers can be attributed in part to differences in the way knowledge is stored in memory and applied to solve problems.

3.2.1 Constructivism: Constructing (and Making Sense from) Our Knowledge

Perhaps the best way of appreciating the constructivist view of learning is to contrast it to its predecessor, the behaviorist view. The behaviorist approach to teaching an individual a complex process is to break up the process into component parts, teach the individual each component, and then teach the individual how to string together the various components until ultimately the desired behavior is obtained. Note the term "desired behavior." From the behaviorist perspective, the process is learned once the individual exhibits behavior that displays competence.

Conspicuously absent from the behaviorist approach are two things. The first is an interest in the cognitive mechanism used by the individual to learn the complex process. This would seem to be an important consideration since knowledge about learning might provide insights into how to shape instruction to make learning more efficient. Recent cognitive research, in fact, suggests that a complex process cannot be learned by decomposing it and teaching individuals its subprocesses without regard to the context within which the complete process will be performed. Knowing how the subprocesses interact within the context of performing the entire process is as important as knowing how to perform the individual subprocesses. In short, knowing each individual subprocess does not "add up" to understanding the entire complex process (Resnick & Resnick, 1992). Also absent from the behaviorist approach is an interest in whether or not the process learned makes sense to the individual. This also would seem to be an important consideration because, if the process learned conflicts with knowledge already possessed by the individual, then the individual either will not be able to accommodate in memory the process learned in any meaningful sense, or will construct parallel, conflicting knowledge structures.

To summarize, the focus of the behaviorist approach is the final manifestation of "competence" by the subject, not whether the knowledge learned makes any sense to the subject or whether the subject will be able to use the knowledge learned in novel contexts. Perhaps the behaviorist approach might be better described as training rather than educating.

Constructivism, which has its roots in the ideas of Jean Piaget, takes the point of view that individuals actively construct the knowledge they possess. This construction of knowledge is a life long, effortful process requiring significant mental engagement by the learner. Further, the knowledge that we already possess affects our ability to learn new knowledge. If new knowledge that we are trying to learn conflicts with previously constructed knowledge, the new knowledge will not make sense to us and may be constructed in a way that is not useful for long-term recall or for application in a variety of situations (Anderson, 1987; Resnick, 1983, 1987; Schauble, 1990; Glasersfeld, 1989, 1992). In contrast to behaviorism, prior knowledge and sense making are very conspicuous in the constructivist view of learning.

Ernst von Glasersfeld on Constructivism

*. . . [constructivism] deliberately discards the notion that knowledge could or should be a representation of an observer-independent world-in-itself and replaces it with the demand that the conceptual constructs we call knowledge be **viable** in the experimental world of the knowing subject (Glasersfeld, 1989, p. 122).*

. . . knowledge cannot simply be transferred by means of words. Verbally explaining a problem does not lead to understanding, unless the concepts the listener has associated with the linguistic components of the explanation are compatible with those the explainer has in mind. Hence it is essential that the teacher have an adequate model of the conceptual network within which the student assimilates what he or she is being told. Without such a model as a basis, teaching is likely to remain a hit-or-miss affair (Glasersfeld, 1989, p. 136).

. . . the fact that scientific knowledge enables us to cope does not justify the belief that scientific knowledge provides a picture of the world that corresponds to an absolute reality (Glasersfeld, 1989, p. 135).

. . . if I want to "orient" the conceptual construction of others, I would do well to build up some idea as to what goes on in their heads. In other words, in order to teach, one must construct models of those "others" who happen to be the students. Only by operating on the basis of a more or less adequate model of the students' conceptual structures can one present the required "knowledge" in ways that are accessible to the students. And students obviously do not come as blank slates. They have their own constructs, as well as theories of how and why their constructs work. Such constructs or theories may be considered "misconceptions" from the teacher's point of view, because they are incompatible with the concepts and theories sanctioned by the particular discipline at the moment. Nevertheless, they make good sense to the students, precisely because they have worked quite well in the context of the students' interests and activities. And because these concepts and theories make sense to the students, they also determine to a large extent what the students see. Hence, it is often necessary to do a certain amount of dismantling before the building up can begin (Glasersfeld, 1992).

Constructivism has important ramifications for learning and instruction. In the constructivist view, the learner's mind is not a blank slate upon which new knowledge can be inscribed. Knowledge previously constructed by the learner will affect how he or she interprets the knowledge that the teacher is attempting to impart. In short, learners are not sponges ready to absorb the knowledge transmitted by the teacher in ready-to-use form. From the perspective of instruction, a constructivist teacher needs to probe the knowledge that learners have previously constructed and evaluate whether this knowledge conflicts with the knowledge being taught. If it does, the teacher must take care to guide learners in reconstructing knowledge; otherwise there is no guarantee that learners will accommodate the new knowledge in a way that is compatible with current scientific thought. To ignore learners' preconstructed knowledge makes it highly probable that the message intended by the teacher will not be the message received by the student.

The discussion above would suggest that perhaps much of the confusion that students exhibit in learning scientific concepts might derive from conflicts between previously constructed knowledge and the concepts they are trying to learn. Our discussion would also seem to suggest that simply making instructional presentations more lucid or persistent is not likely to alleviate students' confusion that derives from such conflicts. The research findings on misconceptions, described below, confirm these conjectures.

3.2.2 The Initial State of the Learner: The Role Played by Preconceptions in Learning Scientific Concepts

By the time students enter our classrooms, they have been constructing knowledge for many years. The knowledge constructed by individuals is an attempt to organize experiences and observations so that they make sense and can be used to make predictions. For example, if a typical twelfth grader is asked to predict what will happen when a ball is thrown vertically up in the air, she would probably state that the ball will go up to some maximum height, turn around, and return to the place from which it was thrown. If she were asked to predict what would happen if the ball were to be thrown harder, she would probably say that it would go higher before turning around and returning. These kinds of correct predictions from our constructed knowledge let us function quite adequately on a day-to-day basis.

Along with the constructed knowledge about a ball thrown up in the air, students have, during the course of their lives, constructed their own private understanding of concepts such as speed, velocity, acceleration, and force — concepts that have very specific meanings to scientists but often have different meanings in daily parlance. This body of "private understanding" that students possess prior to receiving formal scientific instruction is usually fragmented, incomplete, and fraught with *preconceptions*, or beliefs about the meaning and application of concepts within scientific settings (DiSessa, 1988; Driver, 1989; Driver, Guesne, & Tiberghien, 1985; West & Pines, 1985). When preconceptions are in conflict with scientific concepts, which is a very common occurrence for students who have not received prior instruction in science, they are called *misconceptions*. (Other terms used in the literature for misconceptions are "naive theories" and "alternate conceptions.")

For example, if prior to taking physics the same twelfth grader were asked to discuss the thrown ball in terms of its acceleration, it is very likely that she would state that the ball would have a large acceleration just after it is released, that the acceleration would diminish as the ball ascends, becoming zero at the very top of its flight, and that the acceleration would again increase as the ball descends. This misconception, in which acceleration is treated as if it were equivalent to speed, is very common (Clement, 1981; Hestenes, Wells, & Swackhamer, 1992; Trowbridge and McDermott, 1980, 1981). If asked to discuss the thrown ball in terms of the forces acting on it, the student would likely state that the thrower gave the ball a large initial force, which propels it along as it climbs. This "force of the hand," the student would claim, is possessed by the ball but diminishes as it ascends, becoming totally "used up" by the time the ball reaches the top of its flight. And as the ball descends, it acquires increasing amounts of a new force — the gravitational force — which makes it pick up speed as it falls back to earth. This type of misconception, which is akin to the medieval theory of "impetus,"[1] has been observed by various researchers (McCloskey, Caramazza, & Green, 1980; Clement, 1982; Halloun & Hestenes, 1985). Many other misconceptions about physics have been uncovered and are reviewed in various sources (Maloney, 1992; McDermott, 1984; Mestre & Touger, 1989; Novak, 1987; Pfundt & Duit, 1991).

Misconceptions are common across the sciences (Anderson & Roth, 1989; Anderson & Smith, 1987; Bishop & Anderson, 1990; Champagne, Klopfer, & Gunstone, 1982; Garnett & Treagust, 1992; Goldberg & McDermott, 1987; Hesse & Anderson, 1992; Thomson & Stewart, 1985). One study in biology investigated students' understanding of how plants made food (Wandersee, 1983). The study, conducted with students from grades 5, 8, and 11, as well as college sophomores, probed students' understanding of the role of soil and photosynthesis in plant growth, and of the primary source of food in green plants. Although students in the higher grades displayed more correct understanding, students from all grade levels displayed misconceptions. These included the following: the soil loses weight as plants grow in it, the soil is the plant's food, roots absorb soil, plants convert energy from the sun directly into matter, plants give off mainly carbon dioxide, the leaf's main function is to capture rain and water vapor in the air, plants get their food from the roots and store it in the leaves, chlorophyll is the plant's blood, chlorophyll is not available in the air in autumn and winter so the leaves cannot get food.

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[1] *In medieval times it was believed that an attribute called impetus could be supplied to inanimate objects, which they could then use as a kind of "fuel" to maintain motion. Once an object used up its impetus, it would cease to move. In fact, Isaac Newton's development of mechanics was hampered by his persistent belief in the notion of impetus for about twenty years (Steinberg, Brown, & Clement, 1990).*

A study of students' understanding of earth science concepts (the same study from which the scenario at the beginning of this chapter was taken), revealed that many students believe that it is hot in summer and cold in winter because the sun is closer to the earth in summer than in winter (Sadler, 1987). Further, students' beliefs about why it was dark at night and light during the day included that the moon blocks out the sun, the sun goes out at night, and the atmosphere blocks out the sun at night. Many of the students displaying these misconceptions had finished an earth science course in which the requisite knowledge was covered. The only difference between the erroneous answers of those who had taken the course and those who had not was that more technical jargon was used by those who had taken the course.

Research findings consistently show that misconceptions are deeply seated and are likely to remain after instruction, or even to resurface some weeks after students have displayed some initial understanding immediately following instruction (Clement, 1982; Halloun & Hestenes, 1985). Heather's earth science teacher expressed surprise — even dismay — when viewing videotapes of Heather's understanding of the concepts taught in class (Pyramid Film and Video). This reaction is very common among science teachers in both high school and college once they fully realize what students' conceptual understanding is following science courses.

Because students have spent considerable time and energy constructing their naive theories, they have an emotional and intellectual attachment to them. Students cling to their erroneous beliefs tenaciously, often explaining away conflicts between scientific concepts and their naive theories by reinterpreting the lessons taught by teachers or by making inconsequential modifications to their theories. A clear example of this phenomenon comes from a study of children's understanding of the earth's shape (Vosniadou & Brewer, as reported in Chi, in press). Children who believe that the earth is square and are then told that it is round picture the earth as round like a pancake, not round like a sphere. If they are then told that it is round like a sphere, these children incorporate the new information about a spherical earth within their flat-earth view by picturing a pancakelike flat surface inside or on top of a sphere, with humans standing on top of the pancake.

What is deceptive is that students often display "understanding" in standardized science tests, in tests constructed by teachers, or in text-embedded tests provided by textbook publishers, thereby giving teachers a false sense of their students' true understanding. Tests that probe for factual knowledge or that do not force students to apply the concepts covered in class in a wide range of situations will continue to show that students "understand" the material covered in class. What is clear is that without some catalyst, such as tests that probe for deep conceptual understanding (e.g., Hestenes & Wells, 1992; Hestenes, et al., 1992) or classroom discussions where misconceptions are addressed, the mental engagement necessary for students to reconstruct their knowledge will remain absent.

Perhaps the most striking evidence that misconceptions are immune to traditional instruction is their prevalence among the general citizenry and even among experienced teachers. For example, in a recent study of misconceptions in astronomy and cosmology, 1,120 adults were asked to answer several multiple choice questions in a survey (Lightman, Miller, & Leadbeater, 1987). The findings revealed that 45 percent of respondents believed that the sun was not a star; that only 24 percent knew that the universe is expanding; and that among those who stated they would be troubled if they found out that the universe was expanding, 92 percent were concerned that the expansion would present a danger to earth. Other studies have revealed that experienced instructors exhibit misconceptions in basic introductory topics (Lochhead, 1980; Reif & Allen, 1992). These data indicate that traditional instruction is not effective at imparting a deep understanding of scientific concepts.

3.2.3 Organization and Application of Knowledge in Problem Solving

Problem solving is ubiquitous in the sciences. Teaching students to become proficient problem solvers is also one of the most challenging tasks in science courses, especially in disciplines that are highly analytical such as chemistry and physics. To understand why it is so difficult for high school and college students to develop problem-solving skills in the sciences, we need only examine the ingredients necessary to be regarded as proficient at solving problems in a discipline such as physics: 1) an understanding of physics principles and concepts, 2) the ability to recognize which principles and concepts apply to problems varying widely in context, 3) a knowledge of procedures for applying the principles and concepts, 4) a knowledge of the mathematical form (equations) for the principles and concepts, and 5) proficiency in the mathematics necessary to execute solutions. Clearly, being a proficient problem solver requires not only multiple proficiencies in these higher-order skills, but also a sophisticated mental management scheme for deciding which among several possible courses of action might prove fruitful, as well as how to piece together the many steps necessary for arriving at a solution once a course of action is selected.

To study such a complex process as problem solving, researchers have focused on investigating the performance of those who are proficient problem solvers, or experts, and those who are beginners but are aspiring to become proficient problem solvers, or novices. The hope is that by comparing the performance of experts to that of novices, insights will emerge on how we might go about making more efficient the time-consuming transition from novice to expert. To date, the majority of expert-novice problem solving studies have been conducted in the context of highly structured domains such as chess (de Groot, 1965), electronic circuits (Egan & Schwartz, 1979), computer programming (Ehrlich & Soloway, 1984) and physics (Chi, Feltovich, & Glaser, 1981; Hardiman, Dufresne, & Mestre, 1989; Larkin, McDermott, Simon, & Simon, 1980).

Findings from expert-novice studies are often discussed within two categories: knowledge organization and knowledge use. Not surprisingly, research findings suggest that experts and novices organize their knowledge in memory rather differently. Currently it is believed that experts organize their knowledge into clusters of related knowledge referred to as "chunks," with the various pieces of knowledge in a chunk governed by an underlying principle or concept. These chunks, in turn, can be envisioned as constituting a richly interconnected hierarchical network, not unlike a pyramid, with the most fundamental principles and concepts occupying the higher levels of the hierarchy, followed by ancillary concepts, and with factual/mathematical information stored at the lowest levels (Larkin, 1979; Glaser, 1992; Mestre, 1991; Mestre & Lochhead, 1990). Within such a model of knowledge, "knowing more" means having 1) more conceptual chunks in memory, 2) more relations or features defining each chunk, 3) more interrelations among the chunks, and 4) effective methods for retrieving related chunks (Chi & Glaser, 1981).

Let me illustrate with an example of an experiment, the findings of which have contributed to the current perception of experts' knowledge organization. In this experiment (Egan & Schwartz, 1979), expert and novice electronic technicians were shown a complex circuit diagram for a very short time and then asked to reproduce as much of the diagram from memory as they could. The experts could accurately reproduce much of the circuit diagram following exposures of only a few seconds, whereas novices could not. The experts were capable of such remarkable recall by chunking several individual circuit elements (e.g., resistors and capacitors) that performed an underlying function in the circuit. For example, several circuit elements in a particular portion of the circuit diagram were chunked together as forming an amplifier, and thus by remembering the structure and function of a typical amplifier, the experts were able to recall the arrangement of the individual circuit components composing the "amplifier chunk." To dispel the notion that the findings were simply the result of the experts having a better memory than the novices, both groups were shown circuit diagrams in which the circuit elements were arranged randomly, with no apparent function. Without the opportunity of chunking individual circuit components into functional units, the experts and the novices were equally poor at recalling the nonsense circuit diagram. The same findings have emerged from similar experiments in domains such as chess (de Groot, 1965) and computer programming (Ehrlich & Soloway, 1984).

There is also evidence that the hierarchical knowledge structure possessed by experts facilitates their ability to learn new related knowledge. For example, children who are experts on spiders are able to understand and recall the salient features of a passage on spiders after reading it, whereas children who are not knowledgeable about spiders cannot (Anderson & Shifrin, 1980). Similar findings have been observed in a study of individuals' comprehension of the game of baseball (Voss, Vesonder, & Spilich, 1980). Individuals possessing considerable knowledge about the game of baseball were able to recall the important features from a passage about a baseball game, whereas baseball-knowledge-deficient individuals recalled nonessential details about the passage. In short, the more one knows about a subject the easier it is to acquire additional knowledge about the subject. To use an analogy, having a highly organized filing system — with each filing cabinet labeled by a main theme, each drawer labeled with a subtheme, and each folder within each drawer clearly denoting a specific sub-subtheme — makes it easy to store and retrieve large amounts of information. On the other hand, a filing system where large numbers of folders containing sub-subthemes are strewn on top of a desk makes a highly inefficient information storage and retrieval system.

Major differences between experts and novices also emerge from investigations of how they use their knowledge to solve problems. One clear difference between the problem-solving behavior of skilled and unskilled problem solvers lies in what problem attributes they cue on while deciding on a strategy for solving a problem. More specifically, shortly after reading a problem, skilled problem solvers cue on the underlying principle(s) or concept(s) that could be applied to solve it (Chi, et al., 1981; Hardiman et al., 1989; Hinsley, Hayes, & Simon, 1977; Schoenfeld & Herrmann, 1982). In contrast, unskilled problem solvers cue on the objects and terminology used in problems as a way of deciding on a method of attack. For example, skilled problem solvers in physics decide that two problems would be solved with a similar strategy if the same principle (e.g., Newton's Second Law, Work-Energy Theorem) applies to both problems; in contrast, unskilled problem solvers base their decisions on whether the two problems share the same surface characteristics (e.g., both problems contain inclined planes, or pulleys and strings). Cuing on the surface characteristics of problems is not very useful since two problems that share the same objects and therefore "look" very similar may be solved by entirely different approaches, as Figure 3-2 demonstrates.

Expert-novice differences in knowledge use also emerge from observing the actions of individuals actively engaged in solving problems (see Figure 3-2). After deciding on the concept(s) that apply to a problem, skilled problem solvers next decide on a procedure by which the concept(s) can be applied, and then, in quantitative domains, they apply the relevant formulas to generate answers. On the other hand, unskilled problem solvers resort to finding and manipulating equations that contain the quantities given in the problem until they isolate the quantity or variable being asked for (Chi, et al., 1981; Larkin, 1981, 1983; Mestre, 1991).

In summary, skilled problem solvers' tendency to conduct *qualitative analyses* of problems prior to executing the quantitative solution distinguishes them from unskilled problem solvers.

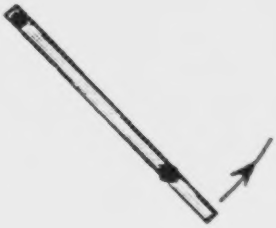
My description of the tendency of novices to use a formulaic approach to solve problems should not be interpreted as a judgment of the approach as useless. Clearly if this approach did not often yield correct answers, novices would have abandoned it in favor of a more fruitful one. This predisposition is more a matter of necessity than choice. Those who are starting to learn a subject do not yet have the appreciation or understanding of its principles and concepts necessary to be adept at knowing when and how to apply them. Equations, on the other hand, are easy to manipulate as long as one's algebraic skills are reasonably honed. Students are able to succeed with this approach because they can narrow down those equations that might be useful by remembering which portion of the textbook the problem came from and matching the variables in the equations to the "givens" in the problem. It is only after considerable experience in solving problems this way that the unskilled problem solver begins

Figure 3-2

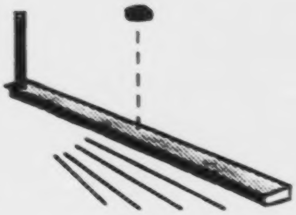
Expert-novice differences in problem solving
(from Mestre, 1991)

The following three physics problems can be used to illustrate differences in the problem-solving behavior of experts and novices:

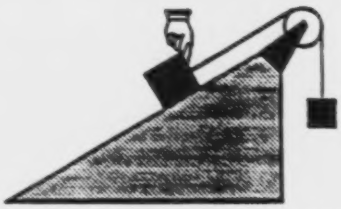
Problem 1: A 1 kilogram stick of length 1 meter is placed on a frictionless horizontal surface and is free to rotate about a vertical axle through one end. A 50 gram lump of clay is attached 80 centimeters from the pivot. Find the net force between the stick and the clay when the angular velocity of the system is 3 radians per second.



Problem 2: A stick of length 1.5 meters and mass 0.2 kilograms is on a frictionless horizontal surface and is rotating about a pivot at one end with an angular velocity of 5 radians per second. A 35 gram lump of clay drops vertically onto the stick at its midpoint. If the clay remains attached to the stick, find the final angular velocity of the stick-clay system.



Problem 3: A 60 kilogram block is held in place on a frictionless inclined plane of angle 30°. The block is attached to a hanging mass by a massless string over a frictionless pulley. Find the value of the hanging mass so that the block does not move when released.



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Question: Which of problems 2 and 3 would be solved most like problem 1? Explain your answer.

Typical Expert's Response:	Problem 3 would be solved most like problem 1 because both involve the application of Newton's Second Law.
Typical Novice's Response:	Problem 2 would be solved most like problem 1 because both involve a rotating stick with a lump of clay attached.

Note that the expert cues on the underlying principle that could be applied to solve the problems, whereas the novice cues on the surface characteristics of the problems.

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Figure 3-2
(cont.)

Question: Describe how you would go about solving problem 1.

Typical Expert's Response:	The clay accelerates as it moves in a circular path. The net force needed to keep the clay going in a circle is provided by the horizontal force between the stick and the clay. Therefore, apply Newton's Second Law and set the net force on the clay equal to its mass times its centripetal acceleration. Then solve for the magnitude of the force.
Typical Novice's Response:	The stick and the clay are both moving in a circular path so I would probably have to use $I\omega$ and $\frac{1}{2}I\omega^2$ for the stick, and mvR and $\frac{1}{2}mv^2$ for the clay. I am told values for the mass of the clay and the stick so I have m and I can find I by looking up the moment of inertia of a stick pivoted at one end in a table and plugging in to get a number for it. The force for something moving in a circle is $\frac{mv^2}{R}$ so I think that I have enough to get an answer.

Note that the expert performs a qualitative analysis during which the applicable principle is identified and a procedure for applying the principle is stated. In contrast, the novice immediately resorts to formulaic approaches, often writing down expressions that are irrelevant for solving the problem (e.g., $I\omega$, $\frac{1}{2}I\omega^2$). Principles and concepts are usually lacking from the novice's approach.

to realize the lack of generality of this approach and begins to shift to concept-based problem-solving strategies.

3.3 Lack of Alignment between Instructional Practices and Current Views of Learning

Given this brief overview of cognitive research on learning and problem solving, the obvious question is, "Do current teaching practices and commercially available curricula in science reflect our best understanding of how students learn and how skilled problem solvers solve problems?" I address this question from three perspectives. First I discuss how science is taught in traditional curricula in grades 1-12. I then turn to commercially available curricula and evaluate whether or not they match current views of learning. Finally, since many argue that tests drive curricula, I also address this question by reviewing assessment practices in science education. The evidence presented indicates that science instruction and curricula do not reflect current views of learning and problem solving.

3.3.1 Traditional Practices for Teaching Science in Grades 1-12

Transmittalist Instruction

Traditional approaches to teaching science consist of presenting material through lectures while students sit quietly "learning" it. This approach, termed "didactic instruction" or "transmittalist instruction," assumes that students can absorb scientific knowledge while passively listening to instructors. A tacit assumption behind this method of instruction is that the ability to understand material being transmitted depends largely on the clarity of the presentation. If a student fails to understand, then making the presentation clearer or more insistent should make the material transparent for the student. (Often, making a presentation clearer or more insistent translates to the teacher speaking slower and in a louder voice.) As we have seen, this view is inconsistent with cognitive research findings. Transmittalist instruction is not optimal for the construction of knowledge by students, but unfortunately, it is optimal for having students misinterpret incoming information in accordance with knowledge that they have already constructed -- knowledge that is often inconsistent with scientific concepts.

Although transmittalist instruction is used almost exclusively in college science courses as well as the majority of science classes in grades 1-12, it would be inaccurate to state that transmittalist instruction is the method of choice of teachers. Transmittalist instruction is part of a vicious cycle fed by two factors. First, we are inclined to teach the way we were taught, and it is very likely that we were taught with a transmittalist approach. Second, the information explosion in science places science teachers under pressure to cover an ever-increasing amount of material. Rather than focusing on teaching a few scientific concepts well enough so that students truly understand them and can apply them in a wide range of contexts, teachers focus on "covering" large bodies of "science facts." This leaves little time for identifying and thinking about the few powerful scientific concepts that constitute the meat of a science course (Anderson, 1987; Arons, 1990; McDermott, 1990; Mestre & Lochhead, 1990; NRC, 1990; Smith & Neale, 1989). Simply learning science facts puts the students in a passive role, encourages memorization rather than the active construction of knowledge, and fails to connect the material covered in class with the student's previously constructed knowledge. Consequently, students lack a solid conceptual foundation after completing most science courses.

These statements should not be construed as meaning that science instruction in American schools consists solely of transmitting facts about science, although research suggests that the weaker a teacher's background is in science, the more likely it is that this will be the case (Anderson & Roth, 1989). Teachers with strong backgrounds in science often model for students activities that are crucial in the practice of science, such as description, explanation, and prediction. Even so, students will largely observe a teacher modeling such activities, rather than actively construct the activities for themselves. Many excellent science teachers may present well-integrated knowledge to students, but students are not actively engaged in constructing such knowledge for themselves.

In defense of teachers, it also should be pointed out that much of the research that argues against a predominantly transmittalist instructional approach is fairly recent, and instructional applications of this research are only now beginning to trickle down to the classroom. It is also true that college instruction in the sciences does not presently reflect current views of learning. Before we have a right to expect science teachers teach to in ways consistent with constructivism, we need to demand the same consistency in the type of science instruction that these teachers receive in college.

Ineffective Teaching of Conceptual Knowledge

The research findings reviewed above suggest that, in order to teach in a way that reflects constructivism and that incorporates the implications of cognitive research on problem solving and conceptual development, teachers need to possess a mental framework consistent with these views that guides their instruction. The mental framework that teachers possess, however, is one based on the transmittalist model that was used in their own schooling. That is, teachers' *cognition of instruction* is incompatible with current views of learning and instruction. Classroom observations at all levels indicate that teachers seldom take into account the conceptual knowledge previously constructed by students (Arons, 1990; Anderson & Roth, 1989; Anderson & Smith, 1987 Smith & Neale, 1989; McDermott, 1990). During the course of instruction, students' ideas about science, their predictions, and their explanations of science phenomena are not probed to monitor whether the concepts being taught are in conflict with students' prior notions.

Science instruction that is specifically structured to encourage conceptual change in students requires that teachers be well versed in three important areas (Anderson & Smith, 1987). First, teachers must possess a command of science content sufficient to distinguish big ideas and methodologies from less useful facts and rote procedures. Without sufficient content knowledge, teachers will be unable to recognize when students' conceptual knowledge is incomplete or inconsistent with scientific concepts. Second, teachers need to have a working knowledge of constructivism and a familiarity with the cognitive research literature as it pertains to learning science. Third, teachers need to have a working knowledge of constructivist instructional strategies for promoting and monitoring students' conceptual understanding.

Teachers' knowledge in these three areas is relatively weak across all grade levels. The weaknesses are greatest at the elementary school level. Lack of science content knowledge (i.e., knowledge of principles, concepts, definitions, problem-solving procedures, and experimental and data-analysis techniques) is most prevalent among elementary school teachers (Schmidt & Buchmann, 1983), largely due to the minimal science requirements imposed by colleges and universities on those wishing to become certified in elementary education. Lack of science content knowledge makes it difficult, if not impossible, for teachers to identify students' misconceptions. In fact, primary school teachers often exhibit conceptual flaws similar to children's misconceptions (Smith & Neale, 1989). Because many elementary school teachers feel unprepared in science (Weiss, this volume), they often spend little time teaching it and are especially loath to teach physics topics, about which they know the least (Smith & Neale, 1989). The science taught in elementary schools is usually right out of textbooks (Weiss, this volume) and, as I argue below, elementary school textbooks offer little more than lessons in scientific vocabulary. Furthermore, teachers at this level believe that they need to know the answers to questions children might ask, and that without an encyclopedic knowledge of science they will be unable to teach it. The view that science is a process of inquiry that allows us to ask questions, design methods for answering them, and organize our answers under a few powerful principles is foreign to most teachers at this level.

At the middle and high school levels, relatively few science teachers meet the course-completion standards recommended by the National Science Teachers Association (NSTA) (Weiss, this volume). A considerable number of teachers teach science subjects in which they received no formal education (Anderson & Smith, 1987; Neuschatz & Covalt, 1988). In addition, high school science instruction is severely lacking in terms of teachers' knowledge of students' thinking and of constructivist epistemology (Berg & Brouwer, 1991); transmittalist instruction predominates in high school science instruction (Weiss, this volume).

Ineffective Teaching of Problem Solving

Problem solving instruction in our schools generally does not emphasize techniques used by skillful problem solvers. In high school physical science courses the emphasis is usually on problem-specific procedures and mathematical manipulations to help students get answers, rather than on the application of powerful ideas and generalizable procedures that could be applied across a wide range of contexts (Mestre, 1991). The lack of emphasis on qualitative reasoning and on integrating conceptual knowledge within problem-solving instruction encourages rote memorization of procedures and formulaic approaches that do little to foster conceptual understanding. The problems that students solve often illustrate a single path to a single answer; the notion that a problem may have multiple solutions or multiple paths to a solution is not stressed.

Although many teachers discuss the role of concepts in solving problems, students often focus on the quantitative aspects of the solution rather than on its conceptual aspects. For example, a typical approach for teaching problem solving in physics consists of cycling through a three-step process: concepts are presented, then how they are used to solve problems is illustrated, and finally students are given lots of problems to solve on their own. Although instructors are usually careful to mention what principles and concepts are being applied when they work out problems in front of a class, they often write down only the equations that result from these applications. Consequently, students perceive the quantitative aspects of the solution as being of primary importance and the conceptual aspects as being abstractions that bear little relevance to generating answers. Furthermore, having students with this perception solve lots of problems on their own may only reinforce a formulaic approach. Students who undergo such a regimen often achieve good grades on exams made up of standard problems, but they fail miserably when asked questions that probe for understanding of the concepts underlying the problems' solutions (Anderson, 1987; Clement, 1982; Hestenes & Wells, 1992; Hestenes, et al., 1992; McDermott, 1991)

At the elementary school level, the solutions to the "problems" that students are given usually require only single words or phrases; in that sense, elementary school students do not solve problems but rather answer questions (Anderson & Roth, 1989; Goldberg & Wagreich, 1990). Students typically are not given open-ended problems that require them to break problems into smaller subproblems, devise mathematical or experimental methods for answering the subproblems, or summarize the knowledge learned from solving problems in a form that makes it conducive to applying it in novel contexts.

Inadequacies in the Teaching of Laboratory and Experimental Skills

Experimentation is at the heart of scientific inquiry. This is perhaps why laboratory work and "hands-on" activities are so prevalent in the teaching of science. Yet a critical analysis of the types of lab activities that students engage in indicates that they do not reflect what scientists actually do in the laboratory. What do scientists do when they practice the art of experimentation? Often, planning an experiment begins with a question or series of questions that are of interest to the scientist, that have not been answered previously, and that he or she thinks can be answered within the laboratory. The scientist then has to decide how to go about planning the experiment: equipment may have to be designed, built, or bought; experimental procedures need to be planned to isolate the variable(s) to be studied; and data analysis techniques need to be planned to extract the relevant information from the experimental output. Findings from the experiment are then analyzed and compared against findings from other, related experiments and evaluated in light of existing theories. The findings may then be used to extend or refute those theories. The entire process is open-ended and may be filled with technical and procedural obstacles. It is safe to say that experimentation in a research laboratory does not proceed with a detailed list of procedural steps which, if followed, will result in a desired outcome.

Clearly it would be unrealistic to demand that experimental work in science classes have all the attributes of experimentation in a research laboratory. We could demand that it reflect some of the activities that scientists actually engage in, however. Unfortunately, laboratory experiments in science classes are fairly cut-and-dried activities, usually designed to verify known phenomena rather than make observations and formulate principles (Goldberg & Wagreich, 1990; McDermott, 1990; Mestre & Lochhead, 1990). The "cookbook" nature of these experiments leaves students with the impression that scientists follow predetermined procedures to arrive at their discoveries (NRC, 1990). Perhaps this view is fed by the assumption of many scientists and educators that laboratory work should support the lecture portion of a science course. Research studies suggest, however, that laboratory work designed to reinforce the concepts covered in lectures adds little beyond what students learn with a lecture presentation alone (Dubravcic, 1979; Kruglak, 1952, 1953; Robinson, 1979).

Of the three important functions that experimental work could serve in science classes — teaching experimental skills; teaching data handling, analysis, and interpretation skills; and teaching the process of scientific inquiry — only the first two are feasible within the structured experiments that students perform. Teaching experimental skills and data analysis techniques are very important aspects of science instruction, and these skills can be rather difficult to teach. Studies indicate that 5th and 6th grade children do not record plans or previous experiments in logbooks, preferring to rely on memory to recall experiments that they had performed over an eight-week period (Schauble, 1990). Children also display biases and strategic weaknesses in experimentation, such as unsystematic searches, failure to control variables, distorting evidence to preserve favored theories, and logical errors in interpreting patterns of data (Schauble, Klopfer, & Raghavan, 1991). By the time they get to college, many students still have not acquired these skills (Arons, 1990). On the positive side, studies have shown that students who perform hands-on laboratory activities are better than those who do not on skills such as using lab apparatus, taking measurements and making observations, analyzing data, and following safety procedures (Kruglak, 1952; Beasly, 1985; McDermott, Piternick, & Rosenquist, 1980a, 1980b, 1980c).

The one function that cookbook labs cannot perform is to teach scientific inquiry. With cookbook labs, students are not asked to consider why the hypotheses or questions under consideration are meaningful, why or how the particular apparatus and procedural steps were selected, and how the experimental findings can be used to construct, support, or disprove scientific hypotheses.

Is the solution to teaching scientific inquiry to turn cookbook labs into open-ended labs — that is, labs where students are given a general problem and general guidelines and equipment to use in designing and executing an experiment? Although open-ended labs are a more accurate reflection of what scientists actually do in the laboratory, there are major obstacles to implementing them in schools. Open-ended labs are much more time-consuming than cookbook labs, and thus they are hard to schedule in the typical one- or two-hour weekly lab periods that students are allotted for laboratory work. Students do a lot more floundering in open-ended labs, and thus classroom management becomes a major problem. Nevertheless, a compromise between cookbook labs and open-ended labs, termed "structured inquiry," is possible and is discussed in a subsequent section.

Commentary on Hands-On Activities

Unfortunately, the research evidence suggests that hands-on activities or instruction in process skills will not ensure meaningful learning, either alone or in combination with conventional fact-based instruction. One problem is that science processes do not seem to consist of unitary skills that can be transferred from one context to another. Observing cell cultures, for example, has little in common with observing formations or with observing chemical reactions. Furthermore, a major component of process skills seems to be content knowledge (e.g., a good observer of cell cultures must know a lot about cells) (Anderson, 1987).

3.3.2 Commercially Available Curricula for Grades 1-12

Textbooks set the tone for science instruction in schools, since many teachers use them as blueprints for instruction (Weiss, 1987, this volume). Unfortunately, commercially available textbooks do little to promote constructivist epistemology, conceptual change, or skillful problem solving. I discuss below some of the problems with commercially available curricula for elementary, middle, and high school students.

Recent evaluations of commercially available elementary school science textbooks indicate that they are fraught with problems (Anderson, 1987; Goldberg & Wagreich, 1990; Mestre, 1991; National Research Council [NRC], 1990). The first thing that is apparent is that elementary school textbook series are largely clones of one another. Many of the same topics are covered each year — not in an attempt to increase students' understanding of the concepts involved, but rather in an attempt to add more details, facts, and definitions with each increasing grade level. New scientific words are highlighted in boldface type to emphasize their "importance." The "main ideas" listed in the back of each chapter are mostly definitions and facts, not ideas. Although rare, some texts do contain useful explanations of concepts, but these are not highlighted nor are students challenged to think about the underlying meaning of these concepts. In attempts to simplify the science, errors are often committed; for example, in the light unit of a third grade science text we find this statement: "Light cannot go around objects" (Cohen, et al., 1989, p. 152). Light, in fact, can diffract, or bend, around objects.

In addition to echoing the view that the material covered in elementary school science textbooks is a random collection of unrelated topics and facts, other critics point out additional shortcomings (Brown & Campione, 1990). For example, the narrative style used to make the presentations more captivating makes it difficult for the student to distinguish fact from fantasy. Furthermore, presentations assume a developmental progression, such as categorizing shapes and colors in first grade, animals by habitat in fourth grade, and vertebrates and invertebrates in eighth grade. However, no apparent rationale is provided for how each activity prepares students for the next, more "advanced," activity or how this progression will help students form a coherent view of science. Finally, in the problems and exercises provided there is an almost total emphasis on recalling facts (e.g., "what happens" types of questions) rather than on explaining phenomena (e.g., "why does it happen" types of questions). Without the mental engagement necessary for conceptual change, students often distort what they read because of strongly held prior beliefs that conflict with textbook passages (Anderson, 1987).

For students who are taught science from such textbooks, "understanding" means that they are prepared to answer recall questions on the material, since this is the only type of understanding they are asked to display (Anderson & Roth, 1989). Thus the learning that takes place consists of learning facts about science, not learning science — rarely are students asked to apply knowledge or perform activities in which scientists engage such as describing, explaining, predicting, and controlling the world around them.

From the publisher's perspective, writing elementary school science textbooks that emphasize factual knowledge is an excellent idea in terms of marketing considerations. A curriculum that portrays science as a body of facts is a curriculum that any teacher can teach.

Possessing sufficient knowledge of science content, of students' thinking, and of instructional strategies consistent with constructivism become unimportant within a factsbased science curriculum.

Commentary on Biology Textbooks

In summary, most biology textbooks are produced by publishers who are responding to educationally bankrupt market forces. They are written by authors who do not control the content of the books and who are not selected for their knowledge of biology. They are then edited to conform to grade-level readability scores and to accommodate local tastes and religious views. Whatever the educational merits of editing for trade-level readability, even the most casual reading of texts suggest that they are edited by people who know so little of the science that they introduce inaccuracy and confusion. Last, but not least, the current textbooks are not interesting; they fail to convey the fascination and wonder of living systems, thereby convincing many students that the study of biology is an onerous task. (National Research Council, 1990, p. 32).

At the middle school level, except for cosmetic changes, the textbooks remain similar to those at the elementary school level (Harmon & Mungal, 1992a, 1992b; NRC, 1990, Swartz, 1991). The "factual flavor" is very much alive at this level as well. For example, at the very beginning of a popular middle school science textbook, we find the following definition of science: "Science is the knowledge of all the facts that are known about the world and the methods or processes used to learn or explain these facts" (Feather, Ortleb, Blume, Aubrecht, & Barefoot, 1990, p. 6). The remainder of the book is long on the facts of science and short on the "methods or processes used to learn or explain" the facts. The laboratory activities that accompany middle school curricula do not promote a spirit of inquiry, but rather are designed to verify known phenomena. Such lab activities promote an authoritarian view of science as a body of factual knowledge that is revealed only if the scientific method is followed (Pizzini, Shepardson, & Abell, 1991).

High school biology textbooks also suffer from including excessive amounts of factual science information. For example, a recent review of a high school biology textbook revealed an average of 109 new terms per chapter in its 30 chapters (Sutman, 1992). Another common complaint from scientists is that biology textbooks are fraught with content errors (NRC, 1990). The same biology textbook mentioned above averaged one error per page. The emphasis on (often inaccurate) factual information in textbooks leaves little opportunity for inquiry activities and for extracting and making sense of the major concepts underlying biology.

In high school physical science courses, where problem solving begins to play an important role, popular texts illustrate problem solving as a process of algebraic manipulation, by illustrating worked-out examples in which so-called basic equations are found and manipulated to yield answers (see Figure 3-3). Little or no attempt is made to discuss the application of concepts or ideas, which would alert students to the importance of conceptual knowledge in solving problems. Also, rather than selecting textbooks on the basis of accuracy of presentation and sound pedagogic strategies, high school teachers often select texts in terms of how attractive they look (McDermott, 1990).

Very few science curricula reflect research findings on learning and problem solving. Many of the existing exemplars are often labeled "experimental," however, or are still under development and not commercially available. Some new, innovative physical science curricula for grades 1-12 are listed in a recent article (Salinger, 1991).

3.3.3 Traditional Student Assessment Practices

An examination of traditional student assessment practices indicates that they do not support a curriculum that focuses on the teaching of conceptual knowledge and problem-solving skills. For the moment let us consider the types of standardized achievement tests used for purposes of public accountability, a major use of student assessment today. An example of this might consist of evaluating a school system's performance by assessing students' knowledge in numerous subjects. Three problems plague standardized achievement tests: 1) the format of the tests, 2) the behaviorist assumptions underlying them, and 3) the effect these tests have on the curriculum.

The format of the vast majority of standardized achievement tests administered to the students in a school or district is "multiple choice." Recent studies that have scrutinized the questions asked in multiple choice achievement tests in mathematics and science indicate that they focus on the recall of routine factual knowledge, not on problem solving (Harmon & Mungal, 1992a, 1992b; Murnane & Raizen, 1988; Resnick & Resnick, 1992). Furthermore, the multiple choice format conveys the impression that the answer is already known, and so imaginative methods for obtaining the answer are not expected. Finally, selecting the correct answer from an array of choices is not an accurate depiction of what people do when they solve problems in the real world.

Figure 3-3

Worked-out example based on an actual problem from a popular high school physics textbook illustrating an algebraic solution with no indication of how or why conceptual knowledge is useful in selecting the appropriate "basic equation" (from Mestre, 1991)

A large chunk of ice with a mass of 12 kilograms falls from a roof 7.5 meters above the ground. a) What is the kinetic energy of the ice as it reaches the ground? b) What is its speed as it reaches the ground?

Given: $m = 12\ \text{kg}$

$g = 9.8\ \text{m/s}^2$

$h = 7.5\ \text{m}$

$KE_i = 0$

$KE_i = 0$

Unknown: a) KE_f b) v_f

Basic Equation: $PE_i + KE_i = PE_f + KE_f$

Solution:

a.

$$PE_i + KE_i = PE_f + KE_f$$

$$mgh + \frac{1}{2}mv^2 = PE_f + KE_f$$

$$(12\ \text{kg})(9.8\ \text{m/s}^2)(7.5\ \text{m}) + 0 = 0 + KE_f$$

$$880\ \text{J} = KE_f$$

b.

$$KE_f = \frac{1}{2}mv_f^2$$

$$v_f^2 = \frac{2KE_f}{m} = \frac{(2)(880\ \text{J})}{(12\ \text{kg})}$$

$$v_f = \sqrt{147\ \text{m}^2/\text{s}^2}$$

$$v_f = 12.1\ \text{m/s}$$

Multiple choice achievement tests tacitly enact a behaviorist perspective by assuming that complex knowledge can be tested by decomposing and decontextualizing it with an "archipelago" of questions, the sum of which is supposed to equal the "continent" of students' knowledge. As pointed out above, however, cognitive research indicates that knowing the separate parts is not equivalent to knowing the whole.

Finally, accountability tests tend to drive the curriculum (Lomax, West, Viator, & Madaus, 1992; Resnick & Resnick, 1992). Teachers feel considerable pressure to have their students "measure up" on achievement tests. A poor showing on an achievement test by a particular teacher's class, a particular school, or an entire district may have far-reaching consequences, such as affecting teacher salaries, school budgets, or academic ratings for the school or district. Therefore, an inordinate amount of time is spent by teachers "teaching to the tests" in order to improve students' performance. The result is that students are taught a collection of definitions and bits of isolated information that will allow them to "get the right answer" on the tests, rather than a cohesive body of knowledge and the analytical skills to use that knowledge to solve novel problems.

In summary, current student assessment practices, as implemented in standardized achievement tests used by schools for purposes of public accountability, only guarantee that what is taught closely reflects what is assessed. In other words, what is not assessed is not likely to be taught (Resnick & Resnick, 1992). Perhaps the most efficient method for reforming science education is to design assessment instruments that require a demonstration of conceptual understanding and genuine problem-solving skills.

3.4 Factors Necessary to Bring About Alignment between Instructional Practices and Current Views of Learning

In the section above I argued that current instructional practices are poorly aligned with our best understanding of learning and instruction based on cognitive research findings. In this section I discuss the types of changes necessary to bring about alignment through reforms needed in the teaching of 1) conceptual knowledge, 2) problem solving, and 3) scientific inquiry. I also address the types of bold reforms necessary to bring about desirable changes in commercially available curricula and in assessment practices.

3.4.1 Reforming the Teaching of Scientific Concepts

Teaching that simply transmits knowledge to students is not optimal since the scientific knowledge being transmitted will likely conflict with knowledge already possessed by the student. Under transmittalist instruction, students often interpret the incoming knowledge in terms of previously constructed, erroneous knowledge. Hence the knowledge that the teacher attempted to impart may not be equivalent to the knowledge that the student acquired. What are important ingredients for teachers to incorporate into their "cognition of instruction" in order to optimize students' learning of scientific concepts?

In shaping instructional approaches for imparting scientific concepts, teachers need to keep in mind the conditions under which students overcome misconceptions. Posner, Strike, Hewson, and Gerzog (1982) argue that four conditions need to be present in order for students to undergo a conceptual change: 1) Students must become dissatisfied with their existing conception; if students believe that their (erroneous) conception accurately describes scientific phenomena, they will not see a compelling need to change it. 2) Students must possess some minimum of understanding of the scientific concept; without some such initial understanding, students cannot begin to appreciate its full meaning. 3) Students must view the scientific concept as plausible; if the scientific concept is incompatible with other concepts residing in the students' memory, it is not likely that serious consideration will be given to it. 4) Students must view the scientific concept as useful for interpreting or predicting various phenomena.

Although there is no single, optimal instructional approach for bringing about conceptual change, the four conditions above suggest the presence of some essential ingredients in crafting instruction designed to encourage conceptual development (Anderson, 1987; Scott, Asoko, & Driver, 1992; Duckworth, Easley, Hawkins, & Henriques, 1990; Mestre & Lochhead, 1990; Neale, Smith & Johnson, 1990; Smith & Neale, 1989). First, instruction should take into account students' beliefs; we should listen to students' ideas about science and not just transmit our ideas about science to students. Only by probing for understanding will teachers be able to determine when students possess misconceptions that are in conflict with the scientific concepts targeted for instruction. In addition, teachers need to possess considerable knowledge of science content in order to be able to determine whether the conceptions held by students are misconceptions. Furthermore, when a misconception is identified a teacher needs to be able to induce dissatisfaction in students in order to initiate the process of conceptual change. Creating dissatisfaction requires that the teacher be able to challenge students by providing discrepant events that illustrate inconsistencies between their belief and scientific phenomena. When discrepant events are presented or experienced, students need to debate and discuss the scientific concept in view of both their beliefs and the discrepant events. The teacher then needs to help students appreciate the value of the scientific conception in terms of its consistency with other scientific concepts, and its value in interpreting other phenomena and making predictions. Finally, the teacher needs to guide students in reconstructing their knowledge. Figure 3-4 provides an example of an approach for helping students overcome the "force of the hand" misconception discussed above.

The major ingredients in conceptual change teaching place heavy cognitive demands on teachers. The teacher must perform these tasks "on the run," often while attempting to maintain a delicate balance between argumentation and order within the classroom. As stated above, conceptual change instruction requires that teachers possess three types of knowledge: science content, concepts already possessed by students prior to science instruction, and instructional strategies to facilitate and monitor conceptual change.

Helping teachers form a new vision of learning and instruction that incorporates these three types of knowledge may seem an impossible task given traditional teacher education practices. Reshaping pre-service and in-service teacher education programs may be difficult but is certainly not impossible. What is clear is that some significant changes in teacher education programs are necessary and that the changes must meet needs that differ across grade levels. The science content knowledge of elementary and middle school teachers has to be upgraded, but this does not mean that in-service and pre-service teachers need to take an inordinate number of science courses. We need to be selective, to pare down the number of science topics that teachers study and concentrate on giving them a thorough understanding of a few topics rather than a superficial understanding of most of the scientific knowledge from this and the previous century. Furthermore, teachers need not only to experience science instruction in college from an inquiry perspective, but also to become well-versed in teaching science in this fashion. Possessing a thorough conceptual understanding of selected science topics and having a solid grounding in inquiry instruction will allow elementary and middle school teachers to teach a few scientific concepts well and will allow them to provide students with a better perspective of what "doing science" really is. The view that "less is more" in teaching science content is advocated for all levels of science instruction (Arons, 1990; McDermott, 1990; Mestre & Lochhead, 1990; NRC, 1990; Sutman, 1992).

Figure 3-4

One approach for helping students overcome the "force of the hand" misconception (from Mestre, 1991).

Probe for misconception: Toss a ball vertically up and ask students to enumerate the forces acting on it when the object is halfway to the top of its trajectory.

Ask questions to clarify students' beliefs: Does the "force of the hand" change in magnitude or direction? What happens to this force at the top of the trajectory and on the way down? Is this force active in other situations, such as rolling a ball on top of a horizontal surface? When does the "force of the hand" act on the ball?

Suggest discrepant events that contradict students' beliefs: Suppose I push on you -- how do you know when I stop pushing on you? How does the object "know" that the "force of the hand" is still acting on it? If the object experiences the "force of the hand" after it leaves the hand, why can't one control this force while the ball is in the air?

Encourage discussion and debate: Promote fruitful, nondisparaging debate among students as they take different sides in the ensuing argument. Encourage students to apply physics arguments, concepts, and definitions.

Guide students toward constructing scientific concepts: How one guides students depends on their awareness to the teacher's questions and the issues raised during the discussion and debate. One could involve students in

- a synthesis of their responses to questions and situations, with a discussion of how consistent those responses are with the scientific concept or other observations,
- a discussion of "thought experiments" that in principle could measure the "force of the hand,"
- a discussion of what the motion would be like with and without the "force of the hand" from the perspective of Newton's Second Law,
- the design and execution of experiments to test hypotheses.

Reevaluate students' understanding: Ask questions and pose situations that allow students to display whether or not they have acquired the appropriate understanding:

- When is the "force of the hand" acting on a ball that is thrown up in the air?
- What are the forces acting on a cannonball shot out of a cannon while it is airborne?
- What is the difference, if any, between the cannonball and the thrown ball?

The inadequacy of teachers' knowledge of students' beliefs about science and about scientific concepts is a persistent problem across all grade levels. Although there is a large, ever-increasing body of research on students' preconceptions and misconceptions, many pre-service as well as in-service teacher education programs either ignore this pertinent body of knowledge or simply give it lip service without adequately attending to it. It may seem a herculean task to instruct teachers in the countless misconceptions that students are likely to possess. Research indicates, however, that although misconceptions are prevalent, the number of distinct misconceptions in any given topic is quite small (Mestre & Lochhead, 1990). Thus the task of providing teachers with a perspective on students' beliefs as they study science content is quite manageable.

Perhaps teaching teachers instructional strategies that foster conceptual change is the most difficult of the tasks, largely because most of the cognitive research effort to date has focused on studying learning rather than instruction. Nevertheless, some promising instructional strategies that reflect both the constructivist view of learning and the need to consider students' prior knowledge are beginning to emerge (Anderson & Smith, 1987; Scott et al., 1992; Brown & Campione, 1990; Minstrell, 1989; Clement, 1991; Smith & Neale, 1989; Van Heuvelen, 1991). These instructional strategies have many features in common, the most obvious one being that students are actively engaged in constructing scientific knowledge. The teacher takes on the role of coach rather than transmitter of knowledge. Classroom discussions of concepts are common, either within collaborative groups of three or four students, or with the entire class with the teacher as moderator. These discussions focus on scientific concepts, with students' prior notions being probed by the teacher and by other students. This approach should not be confused with discovery learning, where students are urged to discover scientific concepts on their own. Scientific facts and concepts are transmitted to students in conceptual change instruction, but the emphasis is active engagement by students in constructing accurate mental representations of scientific concepts. Figure 3-5 contains an example of how such a discussion, regarding the concept of acceleration, might proceed in a high school physics classroom.

Two caveats should be mentioned. Some may get the impression from the foregoing discussion that conceptual change instruction is tantamount to a crusade for the finding and eradicating of students' misconceptions. This is not the case. The constructivist view takes note of the fact that students' conceptual knowledge evolves in time, and many misconceptions will disappear naturally as students gain expertise (Driver, 1989). The foregoing discussion should

Figure 3-5

A classroom dialogue for clarifying the concept of acceleration (from Mestre, 1991).

The teacher has previously introduced the concept of acceleration. The teacher now presents some simple situations in order to explore the students' understanding of the concept in concrete contests.

Teacher: Suppose I toss a ball straight up in the air like this *(demonstrates)*. What is the ball's acceleration at the top of the trajectory?

Student 1: Zero.

Student 2: Yeah, zero.

Teacher: Why is it zero?

Student 1: Well, at the top the ball stops moving, so the acceleration must be zero.

Teacher: OK. If I place the ball on the table so that it doesn't move, is it accelerating?

Student 2: No. It's not moving.

Teacher: What if I roll the ball across the table so that it moves at a constant velocity *(demonstrates)*. Is the ball accelerating in that case?

Students 1 and 2: Yeah.

Student 3: No way! If the ball is rolling at a constant speed it doesn't have any acceleration because its speed doesn't change.

Student 2: No . . . listen. The ball had to have an acceleration to get to the speed it had.

Student 3: Yeah, but once it rolls at a constant speed it can't have any acceleration, 'cause if it did it would roll faster and faster.

Student 2: I'm not sure. You're confusing me.

Teacher: What's the definition of acceleration?

Student 1: It's the change in speed over the change in time.

Teacher: Close but not quite. It is the change in *velocity* over the change in time. Speed doesn't care about direction but velocity does. At any rate, apply your definition to the ball rolling on the table.

Student 2: Well, I guess since its speed -- I mean, velocity -- doesn't change when it rolls, it can't have an acceleration.

Figure 3-5 (cont.)

Teacher: Do we agree on this case?

Student 1: Yeah.

Student 2: I guess so.

Teacher: So it appears that an object can have zero acceleration if it is standing still or if it is moving at a constant velocity. Let's reconsider the case where the ball is at the top of its trajectory *(demonstrates again)*. What is the ball's acceleration when it is at the top?

Student 3: It would be zero because the ball is standing still at the top. It's not moving -- it has to turn around.

Student 2: I think it might be accelerating because it gets going faster and faster.

Student 1: Yeah, but that doesn't happen until it gets going again. When it's standing still it's not accelerating.

The teacher could pursue various directions from here to attempt to get students to realize that the ball's acceleration is not zero at the top of the trajectory. One might be to pose a related situation. Another might be to revisit the definition of acceleration and ask students to apply it during the time interval just prior to the ball's reaching the top and just after the ball starts its descent.

create the impression that ignoring how students interpret and construct the concepts that are taught in science class leads to inefficient learning.

The second caveat is that the three "knowledges" needed by teachers for conceptual change instruction are inextricably related and should be taught as a package. Teaching teachers science content alone means that they will be able to understand scientific concepts and model the process of doing science for students, but they may still be incapable of monitoring students' conceptual understanding or helping students construct scientific concepts. Conversely, it has been observed that teachers who are weak in science can be taught instructional strategies both for eliciting students' misconceptions and for encouraging discussion and debate. But without an adequate knowledge of science content, they are unable to recognize students' misconceptions or provide discrepant events — unable, in short, to induce conceptual change in students (Smith & Neale, 1989).

Making the transition to conceptual change instruction in an educational establishment with a long-standing tradition of transmittalist instruction will not be easy. Although in-service teachers may be experts in conventional teaching strategies, they will have to begin afresh as novices in conceptual change teaching strategies. The time required to construct the necessary knowledge to become an expert in conceptual change instruction means that progress will be slow.

3.4.2 Reforming Problem-Solving Instruction

Close scrutiny of our previous review of problem-solving research indicates that two ingredients play a major role in skillful problem solving: 1) a substantial, richly cross-referenced, hierarchically organized knowledge base; and 2) qualitative reasoning based on conceptual knowledge. There is research evidence that we can shape our instruction to help students develop in these two areas so that they will display more skillful problem-solving behavior.

Shaping instruction to help students organize their knowledge hierarchically must begin by curbing our tendency to present knowledge in our classes and textbooks in a linear fashion. Students must be provided with a perspective to help them realize that concepts are useful due to their applicability in a wide range of contexts. As new knowledge is presented, students should be assisted in linking this new knowledge to previously learned knowledge and in building a hierarchical structure where ancillary concepts are placed below, and linked to, major concepts. The relationships among major concepts, and between a major concept and its entourage of ancillary concepts, need to be made explicit during the course of instruction. Attending to how we should present and relate content knowledge, as well as to how students organize this knowledge, is as important as the content knowledge itself (Reif, 1986).

Figure 3-6 depicts a way of helping students structure their knowledge. This figure shows two biology teachers' organization of biological knowledge from the "reproduction" portion of a typical introductory biology course. Students should be asked to construct, add to, and refine such treelike structures at different times during instruction in the science courses they take.[2] Another approach that has shown promise in physical science education is to present knowledge hierarchically, with calculational details subordinated to main principles, which are outlined first to provide an overview (Eylon & Reif, 1984). When presented in this fashion, students were better able to recall the knowledge and use it in problem-solving contexts.

Several tasks can be used to encourage qualitative reasoning. For example, problem categorization tasks (Chi, et al., 1981; Hardiman, et al., 1989) are useful for helping students identify and discuss the underlying concept(s) that can be applied to solve problems. The task that students would be asked to perform is not to solve the problems but to read them carefully and discuss which concepts might be fruitful to apply in constructing a solution. One of the virtues of these types of tasks is that teachers can construct pairs of problems that share the same surface characteristics but are solved by applying different concepts (see Figure 3-2). Conversely, teachers can construct pairs of problems that, on the surface, look quite different but are solved by applying the same concept. Having students work with these problem pairs would serve the dual role of alerting them to the usefulness of concepts and dissuading them from the temptation to focus on surface attributes in designing solution strategies.

Other approaches for encouraging qualitative reasoning focus on having students construct qualitative strategies for solving a problem prior to actually generating a quantitative solution. For example, in two different studies (Dufresne, Gerace, Leonard, & Mestre, 1991; Heller & Reif, 1984) physics novices were asked to generate qualitative analyses of problems in which they described the principles, concepts, and procedures that could be applied to solve the problems. As a result these novices displayed increased expertlike problem-solving behavior when compared with novices who followed traditional methods for solving problems. Similar

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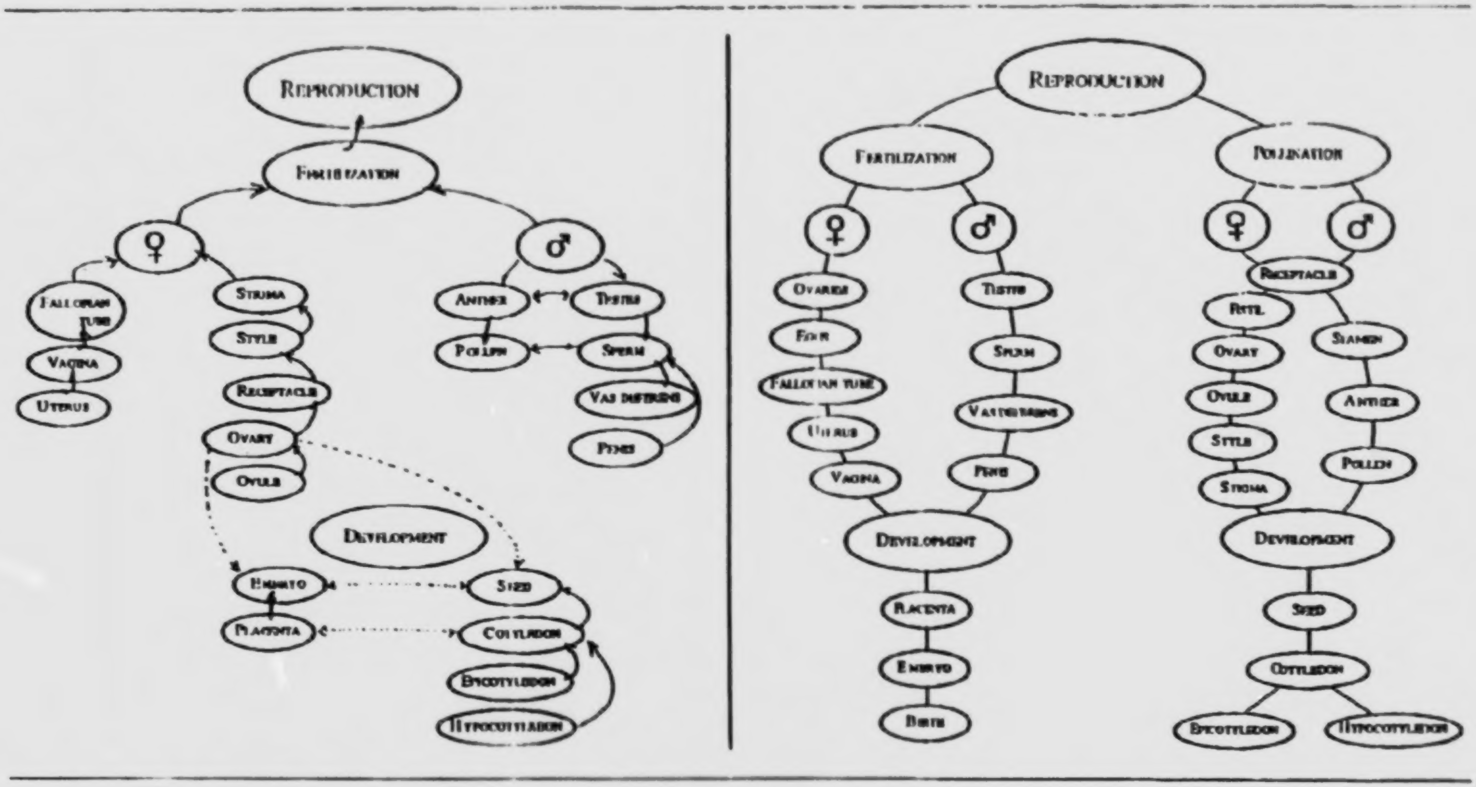
[2] *The organizational structures shown in Figure 3-6 are not unlike the "concept mapping" strategy (Gowin & Novak, 1984), which has been used in the past to help students understand concepts.*

Figure 3-6

Two Biology Teachers' Organization of "Reproduction"


Reproduction
Fertilization
♀
♂
Fallopian tube
Vagina
Uterus
Stigma
Style
Receptacle
Ovary
Ovule
Anther
Testes
Pollen
Sperm
Vas deferens
Penis
Development
Embryo
Seed
Placenta
Cotyledon
Epicotyledon
Hypocotyledon
Reproduction
Fertilization
Pollination
♀
♂
Ovaries
Eggs
Fallopian tube
Uterus
Vagina
Testes
Sperm
Vas deferens
Penis
Development
Placenta
Embryo
Birth
♀
♂
Receptacle
Petal
Ovary
Ovule
Style
Stigma
Stamen
Anther
Pollen
Development
Seed
Cotyledon
Epicotyledon
Hypocotyledon

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findings were obtained in a series of studies (Mestre, Dufresne, Gerace, Hardiman, & Touger, 1992; Dufresne, Gerace, Hardiman, & Mestre, in press) in which students constructed hierarchical qualitative strategies using a menu-driven, computer-based environment that mimicked the qualitative analyses used by experts.

Open-ended problems can also serve as a catalyst for encouraging the use and integration of conceptual knowledge. For example, in "design-under-constraint" problems, students are provided with a real-world design problem and some broad constraints that the solution must satisfy. Examples might be "For five dollars design a meal for four kids that is nutritionally correct and that kids will eat," or "design a disposable container to keep a baked potato warm — the potato should not lose more than 10° C in half an hour" (Salinger, 1991). These types of problems are well received by elementary school teachers because they have multiple "right" answers. Other types of open-ended problems can be designed that may have a single answer but multiple paths to finding it. Examples from biology and chemistry might include determining the optimal salinity of water to be used to ship brine shrimp to a friend, and determining which of two liquids is regular soda pop and which is the diet version (Baron, 1991).

Additional instructional approaches are beginning to emerge that describe methods for helping students develop qualitative reasoning based on conceptual knowledge. Some provide theoretical underpinnings as well as practical suggestions (Arons, 1990); others provide detailed suggestions that incorporate hands-on experiences (Laws, 1991; Rosenquist & McDermott, 1987; Thornton & Sokoloff, 1990); still others even illustrate methods for turning large college physics lectures into interactive environments where students actively discuss how concepts are applied to solve problems (Van Heuvelen, 1991). Some approaches even exploit the emphasis given to language arts at the elementary grades by using collaborative learning techniques within reading lessons to teach science (Brown & Campione, 1990).

3.4.3 Reforming the Teaching of Laboratory and Experimental Skills

I argued above that although cookbook labs may be useful for teaching students some experimental skills and data analysis techniques, they are not adequate for teaching scientific inquiry. I describe here one approach for teaching both experimental skills and scientific inquiry, called "structured inquiry," that addresses these shortcomings (Mestre & Lochhead, 1990). The idea behind the structured inquiry approach is to provide a structure for experimental work that allows students the freedom to explore and learn on their own. Rather than providing all the details of an experiment, as in cookbook labs, the structured inquiry approach simply provides students with a designated topic for the experiments to investigate and the equipment available to conduct the experiment. The teacher's role is to serve as coach, mediator, and facilitator.

The structured inquiry approach cycles through three stages. The first consists of a classroom discussion of experiment design. After the topic for investigation and available equipment are provided, students propose questions and hypotheses and discuss possible experiments and experimental procedures that could be carried out with the available equipment to explore them. Since posing meaningful questions will likely be difficult for students, the teacher must be ready to provide the necessary assistance so that students do not spend an inordinate amount of time floundering. This discussion stage is likely to generate several questions and possible experimentation procedures, all of which cannot be investigated by an individual student. To ensure exploration of all relevant questions, the teacher can then divide the class into collaborative working groups, each having the responsibility of exploring a question or related set of questions.

In the second phase the students carry out the experiments. The teacher needs to circulate and provide guidance and instruction to the various groups on useful techniques for observation, measurement, and analysis. After the experimentation is completed, the groups perform a preliminary analysis of their data and draw preliminary conclusions.

In the third phase the classroom reconvenes for another discussion of the experimental findings. Now the various groups can pool their findings and work on answering the questions or hypotheses posed in phase one. This discussion of the experimental findings might result in the posing of additional questions or hypotheses that need to be explored through experimentation, and hence the cycle might begin again. Structured inquiry proposes a compromise between activities that are doable in the classroom and activities that reflect the experimentation that scientists actually practice in their laboratories.

There are some notable examples of science curricula that model the types of activities described above. The Teaching Integrated Math and Science curriculum (Goldberg & Wagreich, 1990), aimed at the elementary school grades, employs laboratory activities that are of interest to children and lend themselves to a structured inquiry approach. In each activity, students design experiments to explore the relationship between pairs of physical variables (e.g., how the height to which a ball bounces depends on the height from which it was dropped). At the middle school level, the Cheche Konnen project (Warren, Rosebury, & Conant, 1990) focuses on studies of chemistry, biology, and ecology to investigate problems that students believed existed in their school's water supply. The students in this project, who were Haitians with limited English proficiency, designed their own experiments to test a hypothesis they had, namely that water from a particular water fountain in the school tasted better than water from other fountains. Their inquiry began with an in-class experiment consisting of a "blind" taste test of water taken from different fountains in the school. When the data from this experiment did not support their hypothesis, students did not believe the findings. They then decided to carry out another experiment using students drawn from the entire school. Thus another "blind" taste test was set up in the school cafeteria during lunch one day, and additional data were collected. The data from this experiment also refuted the students' initial hypothesis — water from their favorite fountain, in fact, tasted worse than water from other fountains in the school.

These examples of inquiry-based science not only provide more motivation for students but also better reflect the spirit of scientific inquiry. Students' increased motivation often comes from a feeling of ownership derived from the investment they make in designing and carrying out their experiments. Once they reach this state of mind, it is not difficult to excite students about the explanatory and predictive power of science.

3.4.4 Reforming the Commercial Publishing Behemoth

It is difficult to convince an industry that is making considerable profits that their products are inferior. Another vicious cycle appears to be at work in the commercial textbook publishing establishment. Teachers need textbooks to teach, and they naturally feel comfortable teaching from textbooks that are similar to those that they used when they were in school. Thus many commercial publishers simply provide glitzier versions of older textbooks, adding on a teacher's edition and accompanying tests keyed to the chapters in the textbook. This cycle is difficult to break. Those interested in deviating from tradition by writing a textbook that covers fewer topics in greater depth and provides teachers with information both on students' thinking and on instructional strategies are likely to be disappointed. Publishers will likely reject the proposed textbook as too radically different from the best-selling traditional textbooks that school systems buy.

Breaking this cycle will require efforts on several fronts. First, scientists, cognitive scientists, and teachers need to collaborate in developing prototype textbooks to serve as exemplars. These exemplars should:

- cover less content in more depth;
- have a well-thought-out pedagogical progression;
- contain discussions for teachers on students' ways of thinking, stressing the importance of probing and monitoring students' thinking;
- provide suggestions for helping students organize their knowledge hierarchically;
- promote the integration of concepts in problem-solving instruction;
- provide examples of assessment instruments that probe students' understanding of scientific concepts;
- provide examples of inquiry activities that illustrate the scientific paradigm;
- and provide suggestions of instructional strategies that are consistent with constructivist epistemology.

Cadres of teachers need to be educated in the use of the new exemplars; this education must integrate the three types of knowledge discussed above. These teachers would then return to their school systems and serve as resources for other teachers.

This model will require change in the scientific and commercial publishing sectors. States and school systems must demand that the curriculum materials used for instruction reflect a process-oriented approach that focuses on depth of understanding rather than on superficial coverage of science facts. For example, the state of California has significantly impacted the commercial publishing sector by writing process-oriented curriculum guidelines (California State Department of Education, 1990) that textbooks and other instructional materials must satisfy before they can be adopted for use in the state. School systems must also provide time for teachers to discuss instructional innovation among themselves and to receive adequate in-service education. In addition, scientists need to become more involved in educational reform. Finally, commercial publishers must resist the "cloning method" for developing textbooks and take the initiative in developing instructional materials that reflect cognitive research findings in learning and instruction. These types of changes would not only provide students with instruction and curricula consistent with our current understanding of human cognition, but would also ensure that in-service teachers receive on-the-job education in the three types of knowledge needed for effective strategic instruction.

3.4.5 Reforming Student Assessment Practices

If we agree with the premise that "you get what you assess and you don't get what you don't assess," then perhaps the most efficacious way of reforming science education is to design tests for which we would like educators to teach (Resnick & Resnick, 1992). This is, in fact, the approach being taken in *America 2000*. Taking note of the fact that tests tend to drive the curriculum, this blueprint for reform calls for a national assessment system that will set the tone for what will be taught in the schools. The recently formed National Council on Standards and Testing has endorsed the notion of a national assessment system and advocates the construction of high academic standards at the national level that are tied to the proposed assessments.

The types of assessments that are being proposed consist of "performance assessments" and "portfolio assessments" (Resnick & Resnick, 1992). Performance assessments can be thought of as direct evaluations of competence in complex tasks, rather than indirect evaluations that decompose and decontextualize complex tasks into seemingly unrelated subtasks. Portfolio assessments consist of collections of a student's work over a period of time. In science education, a portfolio might consist of a science project or experiment that a student performed over months or perhaps even years.

The types of student assessments being proposed in the current reform movement would more closely reflect the types of problems and questions that scientists consider during the course of "doing science." If the actual science assessments that will eventually emerge do in fact reflect scientists' view of science, then tests driving the curriculum will become a desirable practice rather than one to be eradicated.

3.5 Conclusion

I hope to have left the reader with several impressions. First, learning is a complex process that is individually constructed by learners. Although cognitive science has provided us with many insights into the learning process, the field is relatively young and much remains to be done. Second, today's teachers should not consider themselves just teachers but also students of learning. The new breed of teachers needs not only to be knowledgeable in different areas, but also to be a lifelong learner. Yesterday's notion that "anybody can teach" is dead. Finally, reforming the educational establishment requires a long-term, sustained effort on several fronts. Sporadic forays on specific fronts will not result in systematic, sustained change.

It is also becoming clear that reform, whether it be in curricula or test development or in the design of strategic instruction, needs the involvement and cooperation of scientists, teachers, cognitive scientists, and commercial publishers. The success of the current reform movement will depend on how well these groups pool their wisdom and talents toward devising innovative solutions. Scientists should provide accurate scientific knowledge and insights on problem solving, teachers should provide expertise about children and about the culture of the classroom, cognitive scientists should provide insights on learning and instruction, and commercial publishers should reflect our current understanding about learning and instruction in their products. Only if such collaborations can be effected will science curricula, achievement tests, and instruction in scientific concepts and in problem solving reflect a coherent view.

I close with a quote from T.S. Eliot's *Choruses from the Rock* that captures the essence of the message in this chapter:

> "Where is the wisdom we have lost in knowledge?
>
> Where is the knowledge we have lost in information?"

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4 APPROACHES TO THE SCIENCE CURRICULA FOR GRADES K-12

Senta A. Raizen

A major redesign of traditional science curricula is integral to the current effort to improve science and mathematics education. The contributions and judgments of experienced and well-informed teachers are an indispensable part of this curriculum reform, and implementation of the reform goals in science education will depend on how well teachers understand and are able to carry out the goals and strategies of the new curricula. For this reason, directors and staff of teacher enhancement and development projects must be well acquainted with the directions of current curriculum reform in science and build its salient characteristics into the programs they offer their teacher participants.

This chapter starts with a broad definition of the science curriculum, including key elements that define what students are intended to learn. The definition encompasses not only learning materials (texts, laboratory guides, science kits, and curriculum units) but also guidelines and standards promulgated at various levels (by districts, states, and nationally) as well as science tests. The reason for this broad definition of curriculum is the influence that all these elements exert on the expectations for student learning in science. Teachers and those working with teachers need to be aware of the science content and the philosophy of all the materials that affect what happens in the classroom, whether or not — like textbooks — these are intended for the teacher's immediate use.

The chapter discusses several of these elements in greater detail, with an emphasis on key reform efforts at the national and state levels. Examples of frameworks, guidelines, and tests are given to illustrate how these are used to convey what students should know and should be able to do in science and how classroom practice is expected to change as a result. Furthermore, summaries of some new science curricular materials are provided to illustrate alternative approaches, although all are consonant with major reform directions. Because of the current emphasis on having students in this country do at least as well if not better in science than their contemporaries in other countries, examples are given as well of curricular expectations and approaches in several other countries. In order to give teachers and those providing in-service teachers of education a clear sense of the intent of current reform goals in science education, that part of the chapter concludes with a summary of commonalities and consensus across the rich variety of projects, programs, and recommendations intended to provide alternatives to current curricula and instructional practices in science education.

The chapter then draws some contrasts between the reform consensus and current practice, so that teacher educators and individuals involved in working with teachers have some understanding of the job they need to do. The chapter concludes with a summary of current federal initiatives designed to help institutions and individuals interested in improving science education at the elementary and secondary levels.

4.1 Defining the Curriculum

For the purpose of informing the teacher education and staff development communities of current approaches to the science curriculum, we must begin with defining what the term encompasses. First, one needs to deal with curricular expectations — what students are expected to learn in science. These expectations are expressed in the **intended curriculum** — that is, what teachers are to teach in science at different educational levels as reflected in texts and accompanying materials, laboratory exercises, kit materials and curriculum modules, state and/or district science frameworks and guidelines, and science tests. Second, one needs to compare these expectations to what happens in most classrooms today, namely: the **implemented curriculum** — that is, the intended curriculum as moderated by the teacher and classroom resources, or what students actually have the opportunity to learn in science.

Within these comprehensive definitions of curriculum, there is considerable latitude. The intended curriculum, for example, can be viewed as a sequence of courses that students are expected to take in order to graduate from high school or to enter college; as a set of science topics to be covered; as the "what" and the "how" of science instruction; as the science knowledge, laboratory skills, and thinking skills to be acquired as a result of instruction; as the content of examinations to be mastered by students; or as a combination of several of these. Current reform efforts in science education are characterized by the goal of making these expectations more explicit: During the 1980s, most states increased the number of science courses required for high school graduation; a number of states are now developing or revising curriculum frameworks to guide instruction at the local level; large-scale testing in science has proliferated; professional societies are publishing guidelines as to what ought to constitute the curriculum in their disciplines or across the sciences; at the national level, standards for science curriculum and instruction analogous to those in mathematics are being developed.

The curricular expectations set up through these various external mechanisms are modified through a number of factors operating at the district and school levels, and are further changed by the effect of the intents and competencies of individual teachers on instruction. Thus what the student experiences in the classroom as the *implemented* curriculum is a particular translation of the *intended* curriculum, and may be at considerable variance with it.

4.2 The Intended Curriculum

This section discusses some of the major developments regarding the expectations being set for student learning and achievement in science. The illustrations given of specific efforts are intended to portray major reform directions in the U.S. and in some other countries. Any teacher enhancement or staff development project should take account of these reform efforts and evaluate the way they need to be addressed by the project.

4.2.1 Standards and Assessments

The expectation is that actions taken at all levels of the education system in pursuit of the Year 2000 goals (FCCSET, 1991) will reverse the continuing "bad news" of the low performance of U.S. students on science tests compared with students in other countries (Lapointe, Mead, & Phillips 1989; Lapointe, Askew, & Mead 1992; International Association for the Evaluation of Educational Achievement, 1988) and increase the heretofore modest gains students have made over their own performance over the last twenty years (Mullis, Dossey, Foertsch, Jones, & Gentile, 1991). The goals are to be advanced through the development of national curriculum standards in science (National Council on Education Standards and Testing [NCEST], 1992), modeled on the mathematics curriculum and evaluation standards developed by the National Council of Teachers of Mathematics (1989). The National Academy of Sciences/National Research Council, supported with federal funding, has taken responsibility for creating such standards. Three working groups have been established to deal with curriculum, teaching, and assessment. The curriculum standards will provide a narrative description of what students should learn about science and its applications. The description will be framed in terms of learning outcomes — what students should know and be able to do. The standards will not specify curricula nor prescribe syllabi or courses of study. The teaching standards will provide criteria to select and develop teaching and learning strategies to achieve the curriculum standards. Since they will address the professional development, preparation, and practice of teachers, they should be of particular interest to individuals and institutions providing staff development opportunities for teachers. The assessment standards will provide criteria for guiding the development and implementation of student assessments and program evaluations consonant with the curriculum standards. The curriculum standards are to be released by the end of 1993, the teaching standards and assessment standards, by the fall of 1994.

In addition, both the National Education Goals Panel (1991) and NCEST (1992) have advocated a system of voluntary national achievement tests to be associated with the standards. The twofold purpose of the tests would be to ensure that rigorous curricula are implemented in schools in conformance with the standards and to hold students accountable for their learning. Shepard (1991) has pointed out, however, that using tests to ensure that specified content is learned assumes beliefs about learning stemming from the behaviorist tradition, whereas most recommendations regarding reform of science education are based on a learning model drawing on constructivist psychology (see Mestre, this volume).

Traditionally, such tests as the New York Regents' Examinations and Advanced Placement Examinations have served to define, at least in part, the intended field-specific science curriculum for the highest-achieving students. With the current stress on high achievement for - *all* students, testing and assessment have taken on an increased role. The proliferation of externally mandated tests is notable. Increasingly, states are adding science to the subjects routinely tested with standardized tests, either purchased from commercial sources or developed by the states themselves. Their intent, generally, is to monitor the performance of students and of the local education systems and schools and to identify weaknesses that need to be addressed.

There is much debate, however, about current tests in science, as well as in other fields. The major criticisms are that commonly used science tests do not reflect the nature or the substance of science and provide little information on important objectives of science education. Moreover, unless as in California, Connecticut, Florida, and Illinois the tests are constructed by the state, they are not linked to state frameworks or local curricula. Therefore they are an inappropriate measure of the schools effectiveness in science education. For the most part, tests designed to be administered to large numbers of students are a very limited measure of what these students ought to know and be able to do in science, yet the content of these tests often the operational definition of the science curriculum. Perhaps equally unfortunate is the influence that tests designed for use with thousands of students exert on the testing practices of individual teachers. For ease of administration and scoring, these tests consist largely of multiple choice items — a style of testing that has spread widely throughout individual science classrooms. Yet teachers have a wide choice of assessment strategies available to them that would provide far richer information on their students' science learning than do multiple-choice tests (Raizen, Baron, Champagne, Haertel, Mullis, & Oakes, 1989; 1990). Improvement in science education is in jeopardy unless teacher enhancement programs (as well as teacher preparation programs) deal with this issue.

Since 1969, the National Assessment of Educational Progress (NAEP) has periodically monitored students' science achievement using multiple choice tests administered on a national-sample basis at three age/grade levels. For the science assessment planned for 1994, a new NAEP framework has been developed (Council of Chief State School Officers, 1992) that attempts to accommodate the current consensus on the goals for science education. The 1994 NAEP science framework defines science learning to include acquisition of

1) a core of organized scientific information,

2) the ability to relate scientific concepts to one another and to unfamiliar situations,

3) the inclination to apply science knowledge in practical ways,

4) familiarity with experimental design and the ability to design experiments, and

5) sufficient knowledge and understanding for students to continue their education in science and choose science-based careers, if so inclined.

In addition to testing conceptual science knowledge and understanding, the assessment will also probe students' proficiency in conducting scientific investigations and in practical reasoning. In order to assess students' achievement beyond memorization of factual information, the assessment will include hands-on performance tasks that engage students with physical objects, and open-ended essay-type questions in addition to some multiple choice items. One reason for these major changes in the NAEP's science assessment is to influence classroom practice in directions consonant with current science education reforms: another is to align the NAEP test more closely with the reforms.

4.2.2 Curriculum Recommendations by National Bodies

Reform groups spearheaded by national professional bodies — notably the American Association for the Advancement of Science (AAAS, 1989) and the National Science Teachers Association (NSTA) (Aldridge, 1989) — are recommending quite radical changes in the traditional science curriculum. In addition, several national organizations such as the Association of American Geographers and National Council for Geographic Education (1984), the American Association of Physics Teachers (1988), the American Geological Institute (1991), and the Committee on High School Biology Education (National Research Council, 1990), have developed curriculum guidelines for specific fields of science.

Project 2061. The current AAAS effort to reform science education began in 1985, the year that Halley's comet was visible from the earth. The effort is named Project 2061 for the year that Halley's comet again will near the earth. The naming is symbolic of the long-range reform strategy taken by the AAAS. The first phase of the project consisted of creating an intellectual framework to define the nature of scientific literacy -- what an educated lay person (e.g., a high school graduate) should know about science. The AAAS defined scientific literacy broadly, to include mathematics, technology, and the behavioral and social sciences as well as the natural sciences. The resulting publication, *Project 2061: Science for All Americans* (AAAS, 1989), is serving as the base for the second phase of the project, the construction by six teams of science teachers and district leaders of curriculum models for bringing about scientific literacy for all students. The third phase involves implementing some form of the curriculum models in the country's schools.

The learning goals described in *Project 2061: Science for All Americans* focus on knowledge about the world from the perspective of science — particularly an in-depth understanding of the major concepts that serve to organize factual science information, and their interrelatedness. By the end of high school, students are also expected to develop an understanding of some crosscutting themes — the "big ideas" used by scientists to think about and help explain and predict phenomena in the natural world and the designed world (the world as adapted by humans). These themes include the notion of systems and their interrelated parts, models of various kinds that suggest how things work, stability and change in systems, and the effects of scale on objects and systems. Additional learning goals include knowledge of the scientific endeavor, an understanding of the history of major episodes in the development of scientific knowledge, and the acquisition of habits of mind considered necessary for scientific literacy. Some of these habits of mind are honesty, curiosity, skepticism, the ability to collect information accurately and deal with it critically, and the ability to communicate effectively. Student and teacher curricular materials based on these precepts are likely to be radically different from today's science tests and laboratory manuals. Moreover, schools will have to be organized quite differently, with changed staff roles and teacher preparation and support systems, to make any reformed curricula based on *Project 2061* feasible in the classroom.

Sequential and Coordinated Science. The National Science Teachers Association's Project on Scope, Sequence, and Coordination (SS&C) of secondary school science recommends (1) the elimination of tracking of students, (2) that all students study science for six years, and (3) a coordinated sequence of instruction of all the natural sciences (physics, chemistry, biology, and earth/space science) throughout grades 7-12. As does Project 2061, SS&C urges that less content be taught more effectively. The association has appointed four curriculum committees to identify the science topics to be taught in each discipline at each grade level. The initial effort is concentrating on grade 7, where the first trials are being conducted. According to Aldridge (1991), "the selection of topics and activities for seventh-grade science will be based on relevance of the instruction to the students themselves, their lives, their future, and their immediate environment. . . . There will be a minimum of symbolic or mathematical abstractions. . . . Students will be presented with experience first, then terms and then reinforcement with applications. The emphasis at first will be on concrete rather than abstract ideas and on lessons that involve hands-on activities and experience with natural phenomena." The association has published a guide for curriculum designers (NSTA, 1992) which lays out the core content of what students should learn in science. The guide suggests two approaches for achieving coordination of the science content. The first approach would center on teaching single integrated courses organized around, for example, the great ideas of science (evolution, energy), phenomena (space exploration, the production, distribution, and consumption of food), or science, technology, and society (automobile travel, environmental quality). The second approach would maintain discipline-based courses in the four sciences (biology, chemistry, earth science, and physics) generally, as part of the K-12 curriculum. The sciences could be taught in parallel, with the treatment of topics coordinated (e.g., kinetic theory, light), or they could be taught in sequence in short, quarter-year segments so that connections among them could be drawn more readily and students would be exposed to all the sciences each year. Six implementation centers located across the country are currently developing alternative approaches implementing the NSTA's SS&C principles.

Core and Alternatives. The National Center for Improving Science Education (1989, 1990, 1991) has prepared three sets of reports focusing on elementary, middle, and high school science respectively. For the two lower levels the reports advocate curriculum frameworks that deal with both science and technology, emphasize topics that — while important in their own right — will also build toward an understanding of the major themes that pervade both science and technology; and help to integrate the learning of science content, science skills, and scientific attitudes. The recommended instruction method is to model, at the appropriate developmental level, the activities of scientists and engineers, stressing investigative and problem-solving techniques: Students will engage with a question, problem, or event. They are to be provided with learning experiences that will help them begin to address the question or problem, and will propose explanations or solutions while the teacher introduces needed concepts and other information. They will then be expected to take action, such as designing an experiment to test their explanations or try out their problem solutions.

At the high school level, the Center advocates that all students take science for four years. Assuming the kind of strong foundation of science learning recommended by the Center for the first eight grades, students should be expected to complete their core science learning by grade ten, preparing them for a responsible civic and personal life. The core science requirements would aim to (1) develop understanding of challenging subject matter in the sciences and relate this to historical and contemporary issues, (2) engender the capacity for continued learning and effective communication relevant to scientific and technological issues, and (3) develop informed attitudes toward science and its applications, including its contributions and limitations. For grades 11 and 12, the Center recommends that alternative pathways for the study of science be available to students, including the traditional academic track for college-bound students, a track designed for students planning further technical or engineering education or careers, and a third one preparing students for competent performance in the workplace through a linkage of formal studies in the natural sciences with experiences in actual work situations.

4.2.3 Reforming Curriculum Content

Improving science education involves not only more exposure to science and general curriculum reform, but also more effective instructional materials. College faculty and others concerned with preparing teachers in science and enhancing the knowledge and skills of those already in the classroom will find a wealth of such materials to choose from. The National Science Foundation (NSF) has reactivated its materials development program. Starting in 1987, seven elementary level projects were funded, followed by a round of projects aimed at the middle grades. Professional societies, too, have undertaken curriculum development efforts, as have such independent research and development institutions as the Education Development Center (EDC), the Lawrence Hall of Science, and the Biological Sciences Curriculum Study (BSCS). At the same time, textbook publishers have tried to address some of the criticisms of current science texts, sometimes counterproductively by packing their volumes yet fuller with unconnected bits of information. The promise of technology as a tool for revolutionizing education, and science education in particular, remains largely unrealized, however, despite the development of MBLs (microcomputer-based laboratories), individual simulation units, and "micro worlds" designed to teach such difficult topics as Newtonian mechanics (White, 1984).

The array of innovative curricular materials for science is too large to list, let alone describe, in this chapter. The rest of this section provides summaries of a few examples selected to illustrate different approaches to curriculum reform: modular curriculum units taking up a few days or a few weeks; complete one-year courses; course sequences to span several grades; science curricula specifically designed for urban student populations; technology as an integral instructional tool; technology as a content area in the science curriculum; and integration of mathematics and science in the curriculum. All the curriculum projects described below offer workshops for leaders, teachers, and others who wish to implement the curricular materials, hands-on activities, and learning approaches developed by the projects.

The NSF-Supported Projects. The elementary school curricula supported by the NSF became available through commercial sources in 1991 and 1992. (One of the funding conditions for these projects was that they obtain a publisher or distributor at the outset that would coinvest in the projects and therefore have a strong incentive to market the materials widely.) Three of the curricula are intended as comprehensive K-6 programs: the Life Lab Science Program, the BSCSs elementary science program, and the EDCs Improving Urban Elementary Science.

The Life Lab Science Program is based on an expansion of a garden-based program involving students in hands-on experiences familiar to most teachers and affordable and manageable in most schools. The intent is to relate science concepts and their applications to everyday life. The key component is a garden lab making possible a combination of indoor and outdoor hands-on science activities. Students and teachers together use the school grounds and/or classrooms to establish worm colonies and raise vegetables, herbs, and flowers. In this setting, students conduct experiments and learn to apply scientific processes to maintain their living laboratory. Instructional time varies from two to four hours per week.

The BSCS has designed a K-6 science/health program entitled: *Science for Life and Living: Integrating Science Technology and Health.* The program consists of 28 activity modules intended to serve as a foundation for major concepts in the life and physical sciences, technology, and health. Through the seven years, "students learn about ecosystems and life cycles, properties of matter and forms of energy, transportation systems and plumbing, communicable diseases and physical fitness" (BSCS, 1989). Students are expected to use equipment and hands-on materials and to learn to work in cooperative groups. The stress on technology is somewhat unusual for an elementary school curriculum in this country, although it is an integral part of the curriculum in England and Wales. The study is currently developing a three-year science and technology curriculum for middle school students entitled: *Science & Technology: Investigating Human Dimensions.* The program intends to integrate life, earth, and physical sciences in the context of issues meaningful to middle school students. It will take a thematic approach to science and technology and, as in the elementary curriculum, incorporate cooperative learning strategies. The program has gone through three cycles of field testing and revision, the latest in the 1992-93 school year. Materials should be available shortly after completion of that cycle.

The third elementary school program supported by the NSF and developed by the EDC focuses on science education for children in urban systems, which tend to face particularly complex problems. Teacher development teams were involved in the design of activity-based modules incorporating, as much as possible, natural phenomena that could be explored in the students' immediate environments. In addition to addressing key topics in the life, physical, and earth sciences, the modules aim to integrate teaching of the rest of the elementary curriculum, particularly mathematics and language arts, with science in order to enhance critical thinking, communication, and problem-solving skills. Seventeen modules are available, together with teacher guides usable by both experienced teachers and teachers new to elementary school science. Building on the elementary school modules, the EDC is now developing eight additional modules for grades 7 and 8, also targeted to the needs of urban students.

Private Foundations, Professional Organizations, and Industry. Organizations in this field also have sponsored the development of science curriculum materials. For example, Lawrence Hall of Science received support from the Mellon Foundation and the Carnegie Corporation to develop *Great Explorations in Math and Science*, materials for students ranging from kindergarten through tenth grade. Short units integrate mathematics with life, earth, and physical science and use easily accessible supplies. For example, in *Oobleck: What Scientists Do*, students investigate an unknown substance ("oobleck") and experiment to identify its unique physical properties; they then design a spacecraft that would be able to land on an ocean of oobleck. As of spring 1992, some 31 of these units were available, each taking two to fifteen class sessions. Teacher guides are written to enable teachers with little knowledge in mathematics or science to carry out the activities with their students, and workshops are widely available for additional teacher support.

Another project developed at Lawrence Hall of Science with industry and private foundation funding is *Chemical Education for Public Understanding Project*. The project's units, aimed at middle/junior high school students, promote science learning — particularly chemistry — through addressing such common public issues as toxic waste. The project provides hands-on materials and encourages the involvement of community groups, industry, and scientists in working with students as well as the general public to increase understanding of issues involving chemicals and chemistry.

Among discipline-oriented professional science societies, the American Chemical Society (ACS) has been particularly active. In addition to developing guidelines for the precollege chemistry curriculum, the ACS has also designed an innovative high school chemistry course, *Chemistry in the Community*, or *ChemCom* (ACS, 1988), originally intended for students not planning a science major in college. Rather than using the discipline-based approach of traditional 11th-grade chemistry courses, *ChemCom* deals with chemistry in the context of such societal problems as supplying water needs, understanding food, chemistry and health, and the promise and challenge of the chemical industry. Chemical concepts are introduced as they are needed; in addition, the course incorporates more laboratory and other student-centered activities (surveys, interviews, simulations) than most traditional courses. Another critical feature is the stress on student debates and decision making integrated into every unit. The course has become quite popular — over a quarter million students have taken *ChemCom* — and has proven of interest beyond its originally intended audience. It is now being used at the community college level and as an introductory text for teachers education, as well as being translated into several foreign languages, including Russian and Japanese.

Reorganizing the Curriculum through Technology. One of the science curricular development projects supported by the NSF, *Kids Network*, employs telecommunications to enable upper elementary school students to exchange scientific data across this country and with other countries. The students are also able to communicate with an expert on the scientific problem being investigated, to help them analyze and understand their findings and raise further questions. The first unit introduces the collection and treatment of data by having the students record information on their pets. Other units address acid rain, through students' charting and comparing its presence in various locations; waste disposal, through analyzing the trash produced by participating classes and schools; sources of, and impurities in, water; investigations of weather; foods and nutrients, through an analysis of students' lunches; and solar energy. Thus, in addition to using telecommunications as an integral instructional component, the *Kids Network* units engage students in real-world problems that require active investigations and groups of students working together. Students learn science in combination with other disciplines — mathematics, geography, social studies — and acquire skills in recording and displaying data and communicating about their work. The data the students collect may well contribute to the study of a particular problem: John Miller, the scientist working with students involved in the acid rain unit, proposed including students' *Kids Network* data as an appendix to the National Oceanographic and Atmospheric Administration's report on acid rain (Julyan, 1988). Technical Education Research Centers is the developer of the program; the units are being distributed through the National Geographic Society.

The Voyage of the Mimi, developed by Bank Street College, is built around a 13-part video series of scientific adventure tales featuring the great whales. The videos each carry a story line concerning some mishap or challenge at sea as well as a documentary expedition to locations where science of many different kinds is done. Students are involved in computing the velocity of the ship in several different ways, studying whales and estimating their population size, learning about the marine environment and necessities for human survival, exploring the relationships between environmental conditions and animal behavior, and acquiring skills in the use of scientific instruments and the computer. There are four learning modules — Maps and Navigation, Whales and their Environment, Ecosystems, and Introduction to Computing — which give specific instructions for student activities and projects to accompany the videos. Software is included for computer simulations, games, laboratory experiments, and special graphics. The program offers a rich multimedia experience for upper elementary and middle school students, through which to they are engaged in science and mathematics in a real-life context. A second, 12-part series has been developed featuring an underwater archeology project retracing the trading routes of the ancient Maya. The series includes two learning modules: Maya Math, focusing on the Mayan base-20 number system and the Mayan calendar, and Sun Lab, dealing Mayan astronomy.

Integrating Mathematics and Science. The curricular integration of the sciences and of mathematics with science, particularly in the earlier grades, is a strong theme in most science education reform recommendations. Some integration is built into a number of the new curricular materials, as noted. In addition, several projects have this as their specific purpose. The AIMS (Activities to Integrate Mathematics and Science) Education Foundation distributes curriculum units using this approach. The units are written and tried out by teachers. Some twenty units, ranging from the simple to the complex, have been developed, covering grades K-9. The units are essentially intended for teachers, providing lesson plans, procedures, and some reproducible student pages. For example, *Math + Science, A Solution* consists of 25 investigations focusing on several science and mathematics processes — classifying, measuring, estimating, and gathering and interpreting data. Later lessons deal with hypothesizing, predicting, and controlling variables.

Teaching Integrated Math and Science, developed at the University of Illinois at Chicago, concentrates on concepts central to all science, and approaches mathematics teaching within that context. The underlying assumption is that this will lead mathematics significance and reality. Students do experiments and carry out the following related activities: they draw a picture of the experiment, they record their data in two-dimensional tables (measurement of one variable in terms of the second), they graph their results, and they explain their experiment. The curriculum is intended to develop logical thought processes as well as fundamental science and mathematics concepts.

4.2.4 State-Initiated Reforms

In contrast to their role in the 1960s reforms in science education, states are important actors in current reforms in science education (Raizen, 1991). Curriculum initiatives in the early 1980s, when a "crisis" in science education was rediscovered, largely consisted of states attempting to increase students' exposure to science both in elementary school and in high school. More recently, states have become active in developing or reforming curriculum frameworks to guide science instruction in the schools. At the same time, states have greatly increased assessments of student learning in science: two-thirds of the states now require student testing in science, most of them at three or more grade levels. While standardized short-answer tests still are the common mode, nine states are using performance exercises and open-ended questions.

Increasing the Time Spent on Science. Exposure to pertinent subject matter is an obvious prerequisite for learning in that subject (Raizen & Jones, 1985; McKnight, et al., 1987); hence, increasing that exposure was an early reform strategy favored by the states. By 1987, 26 states had recommended a specific amount of time to be spent on science and mathematics instruction in elementary school; by

For further detail on the projects, materials, and curriculum developers discussed here, as well as for information on additional curricular materials, the reader is referred to the following sources (see references at end of chapter for complete listings):

- ***Sourcebook for Science, Mathematics, and Technology Education, 1992**. Published every year by the AAAS, Washington, DC. The compilation lists curriculum resources (including all the developers mentioned here) as well as a variety of different agencies and organizations concerned with science education.*
- ***Science for Children: Resources for Teachers.** Published in 1988 by the National Sciences Resources Center, Washington, DC. This guide lists curriculum materials and other resources for elementary school science. The Center also develops science curriculum materials for elementary and middle school and plans to publish a guide for middle school science similar to its elementary school guide.*
- ***Educational Programs That Work (National Diffusion Network, 1990).** Compiled by the National Dissemination Study Group and published by Sopris West Inc., Longmont, CO. The 1990 edition describes 19 science programs approved for national dissemination by the U.S. Department of Education. Services available for each of the projects are listed, including dissemination assistance by the National Diffusion Network.*
- ***Science Helper K-8.** This CD-ROM disk contains the curriculum materials produced by several of the elementary school science projects supported in the past by the NSF. The disk provides ready access through several different indices to curriculum materials as well as teacher instructions and supplies needed for classroom implementation. Available from PC-SIG/IASC CD-ROM Publishing Group in Sunnyvale, CA.*
- *The U.S. Department of Education has been charged with establishing a national clearinghouse for science and mathematics curriculum materials and associated products (Eisenhower Clearinghouse for Mathematics and Science Education). Ten regional consortia will be connected with the clearinghouse to ensure that the materials are as accessible as possible. Work on the clearinghouse and the consortia started in 1992, with the expectation that they would be partially operational by late 1993.*

1988, 40 states had increased the number of science courses required for high school graduation (Education Commission of the States, 1984; Blank & Espenshade, 1988), although only four states require as many as three years of science through grades 9-12 (Coley & Goertz, 1990).

As a result of these state actions, enrollments in science courses increased during the 1980s, although the increases were greatest in introductory courses. Introductory biology grew by 20 percent, chemistry by 14 percent, and physics by 6 percent (Blank & Engler, 1992). Enrollments in science courses vary widely by state (Blank & Dalkilic, 1990). For example, in Connecticut, 62 percent of the students have taken first-year chemistry by the time they graduate compared with 26 percent in Idaho and 33 percent in Arkansas, Nevada, and New Mexico. Nevada reports that 65 percent of students have taken first-year biology by graduation, compared with a U.S. average of 95 percent. For first-year physics, several states report 10 to 12 percent of graduating students having taken physics — about half the U.S. average of 20 percent — while others report close to 30 percent, and Connecticut reports 36 percent.

Participation in science courses also differs widely by race and ethnicity. For example, Kolstad and Thorne (1989) found, using data from transcripts of a nationally representative sample of 1987 high school seniors, that 70 percent of graduating Asian students had taken chemistry, compared with 48 percent of white students, 30 percent of black students, and 29 percent of Hispanic students. Some inequalities also exist between males and females: 60 percent of enrollees in physics are male; 55 percent of enrollees in advanced/second year biology are female.

State Frameworks. Starting in the late 1980s, states became more active in their concern about the *content* (as contrasted to the *length*) of the science curriculum. A few states, notably New York, have had a long tradition of providing state-constructed syllabi as guides to local districts and schools, with varying degrees of adherence expected. As reform efforts in science education have moved forward at the national level, however, more states have been impelled to construct curriculum guidelines and frameworks that would reflect the recommendations of national bodies (see also Weiss, in this volume). To indicate the level of activity, 19 states currently are developing frameworks to be completed in 1993; nearly as many had completed theirs in the last three years. Only six states have no science framework (Blank & Dalkilic, 1992). In 16 states, the framework or guide has a direct relationship to the state science assessments, defining content topics and skills; in 13 others, the framework provides learning goals and outcomes used to develop the assessments. Twenty-one states use the frameworks or guides to select or recommend textbooks.

Perhaps most prominent among the state curriculum frameworks has been the one developed by California. In part the reason that California's framework (California Department of Education, 1990) has received considerable attention is that the state is making a concerted attempt to implement the recommendations of its framework through a combination of teacher training and staff development projects, revisions of the state tests in science, and insistence that curriculum materials approved through the state adoption process be aligned with the framework. California's framework has also received attention because of its innovativeness. The framework takes seriously the current reform emphasis on such higher-order processes as conceptual understanding, problem solving, and reasoning rather than concentrating on basic skills and memorization of a myriad of seemingly unconnected facts and concepts. It advocates emphasizing the nature of science throughout the curriculum through having students experience the practices and ethics of science in their own work. At the same time, students are learning about the system in which scientists operate, and they begin to deal with some of the controversies that arise when society applies scientific knowledge to resolve contemporary problems (e.g., related to the environment, conservation, the food supply, or health and medical issues). Following the Project 2061 recommendations, the California framework also advocates organizing the curriculum based on the major themes of science — the comprehensive ideas that integrate scientific facts and concepts and that apply across the scientific disciplines. Table 4-1 shows the correspondence in the themes emphasized in the California framework and in Project 2061, as well as in the frameworks developed by Arizona and Wisconsin and in the recommendations by the National Center for Improving Science Education (NCISE).

State frameworks vary tremendously in approach, length, and the detail with which they specify topics and objectives. For example, Michigan (Michigan State Board of Education, 1991) includes over 200 objectives in its curriculum guide, together with related concepts and terms; Wisconsin (Wisconsin Department of Public Instruction, 1986) provides sample activities for each of the objectives listed in its guide. Arizona's guide (Arizona Department of Education, 1990), at some 50 pages, is less than a third the length of the guides for Michigan and Wisconsin; it frames its goals for science education in terms of student outcomes and examples of indicators for assessing progress toward these outcomes. California's framework uses about half of its 200 pages to describe in simple prose the content of the physical, earth, and life

Table 4-1

Themes Used in Science Curricula

	Project 2061	Arizona	California	Wisconsin	NCISE
Systems	X	X	X	X	X
Constancy	X		X	X	
Change	X	X	X	X	X
Evolution	X		X		
Models	X	X			X
Scale	X		X		X
Limitations				X	
Diversity		X		X	X
Interaction		X	X	X	
Energy			X		
Cause/Effect		X			X
Structure/Function		X			X

sciences to be taught at four overlapping educational levels (K-3, 3-6, 6-9, 9-12), and the rest on defining the nature of science and the major themes, discussing science processes and the teaching of science, implementation strategies, and instructional materials.

How much state frameworks influence what actually goes on in the classroom remains in question, even when a state such as California takes concerted action to align the framework with instructional materials, assessment, and staff development programs (Little, 1989; Cantlon, Rushcamp, & Freeman, 1990; Fuhrman & Elmore, 1990; Cohen & Ball, 1990a, 1990b). As the development and reform of state frameworks proliferate, spurred in part by participation in the NSF's state systemic initiative program, it will be important to track their effectiveness in improving science education in the schools.

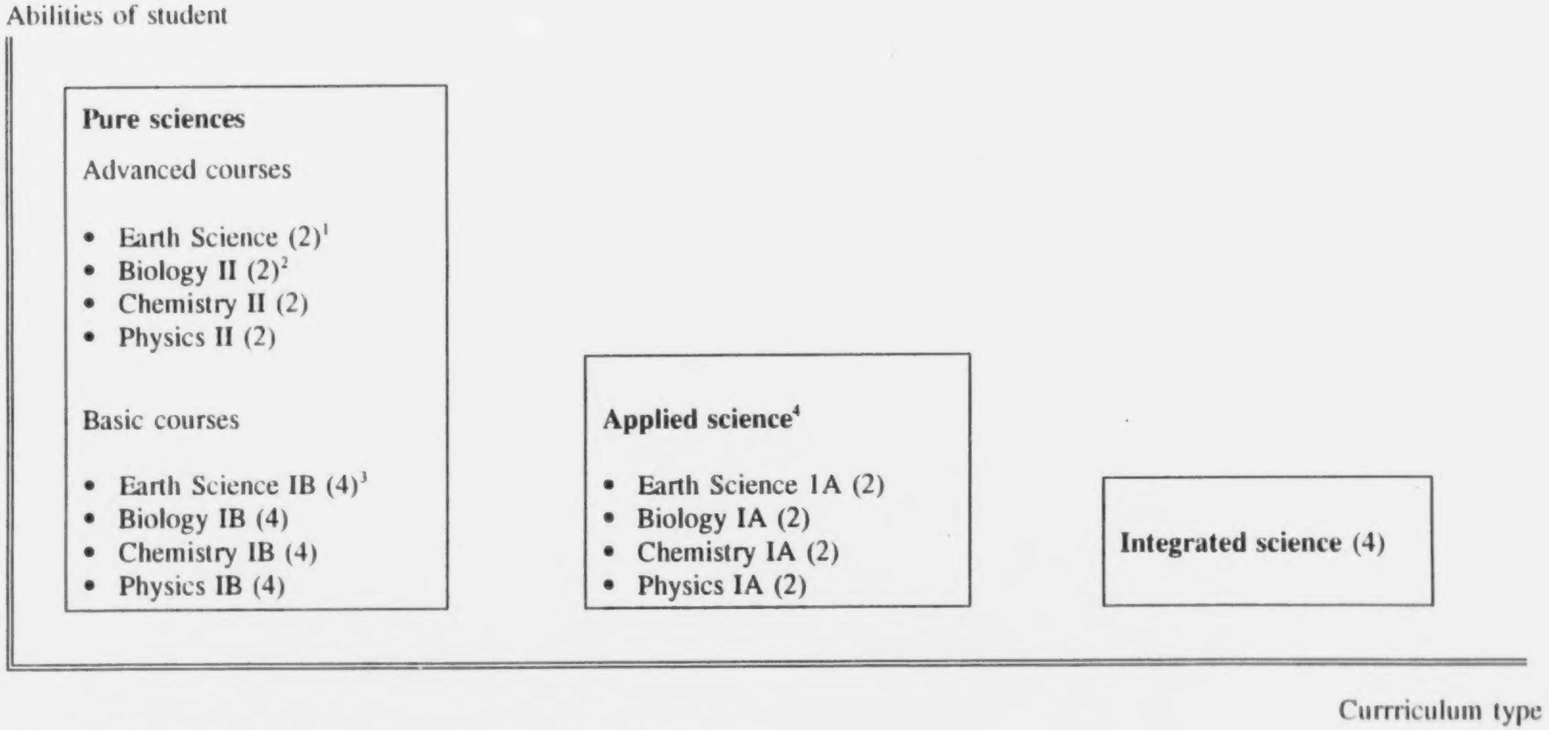
4.2.5 National Guidelines in Other Countries

Interest in the content and pedagogy of science curricula in other countries has increased as the U.S. endeavors to define the world-class standards its own students must meet. Countries with highly centralized education systems, such as France and Japan, have very specific curriculum standards that are intended to guide local curricula and instruction. As with the states, however, their form, intent, and emphasis varies. The descriptions that follow, somewhat more detailed than those for the U.S. projects, are intended to provide a flavor of what other countries expect of their students and the wide variety in how these expectations are fulfilled.

Japan. Curriculum standards in Japan are established by the Ministry of Education and are known as the Official Curriculum or Course of Study; generally they are revised every ten years. Textbooks, developed by publishing companies, are based on the official curriculum and authorized by the Ministry of Education. Local boards select the texts for elementary and junior high schools; each high school selects its own books. Hours of science instruction are specified for elementary and junior high school (three hours per week, with additional science optional in the last grade of junior high school), as are the number of subjects and credits that must be completed in senior high school (more than two science subjects and four credits). Choice is provided for students at the upper secondary level depending on their interests and abilities. Students can opt for more "pure science" courses or more applied treatments, and for learning basic contents across a range of science subjects or specializing in one or two (see Figure 4-1).

Figure 4-1

Newly Revised Upper Secondary School Science Curriculum — 1994
Japan


Abilities of student
Pure sciences
Advanced courses
• Earth Science (2)1
• Biology II (2)2
• Chemistry II (2)
• Physics II (2)
Basic courses
• Earth Science IB (4)3
• Biology IB (4)
• Chemistry IB (4)
• Physics IB (4)
Applied science4
• Earth Science 1A (2)
• Biology IA (2)
• Chemistry IA (2)
• Physics IA (2)
Integrated science (4)
Currriculum type

[1] Numbers in parentheses refer to number of units in the course.

[2] II = Advanced contents of scientific concepts.

[3] IB = Basic contents of scientific concepts.

[4] Applied = Implications for technology, society, environment.

(Source: Yamagiwa, 1990)

Current reform efforts in Japan bear considerable similarity to those being urged in the U.S., at least with respect to their expressed purposes: acquisition of the science content knowledge considered basic and essential for every citizen, greater stress on closeness to nature through observation and experiment, emphasis on problem-solving abilities, and nurturance of a scientific way of thinking and a continuing willingness to learn. Thus, the elementary school guide quoted below notes that emphasis should be placed on direct experiences and contact with natural objects; science learning should focus on problem-solving activities concerned with nature and school involve students in the whole problem-solving sequence, from discovery and formulation of a problem to its solution. The objective is to help children understand key features of natural objects and phenomena and develop scientific thinking and a scientific approach to nature. For lower secondary school, even greater stress is to be placed on observation and experimentation, and instruction in science is to be improved through greater attention to connections with everyday life. In upper secondary school, even though students are provided with some degree of choice in selecting courses matching their interests and abilities, all courses are to stress independent inquiry-based activities in order to strengthen scientific ways of thinking and the ability to form judgments.

Contents and objectives are specified very briefly for elementary school in three areas: living creatures and their environments, matter and energy, and the earth and space. Three paragraphs of guidance on instructional approaches precede the specifications for each grade. The following paragraphs dealing with the topic "matter and energy" for grade 6 illustrate the style of the Official Curriculum:

> **(Objective)**
>
> To get pupils to identify and investigate interactions between changes and functions of water solutions, combustion, electromagnetism, etc. and the causes of these phenomena, and through interesting, problem-oriented activities, to foster ways of looking at and thinking about qualitative changes in substances and materials.
>
> **(Contents)**
>
> *Matter and Energy*
>
> 1) Investigations with various kinds of aqueous solutions, so as to be able to identify what they are made of and how they change.

2) Burning and heating substances and materials, so as to be able to investigate changes in the composition of these substances and in the air.

3) Passing an electric current through a thermal wire or through the coils of an electromagnet, so as to be able to investigate the functions of electricity (Yamagiwa, 1990, 9-10).

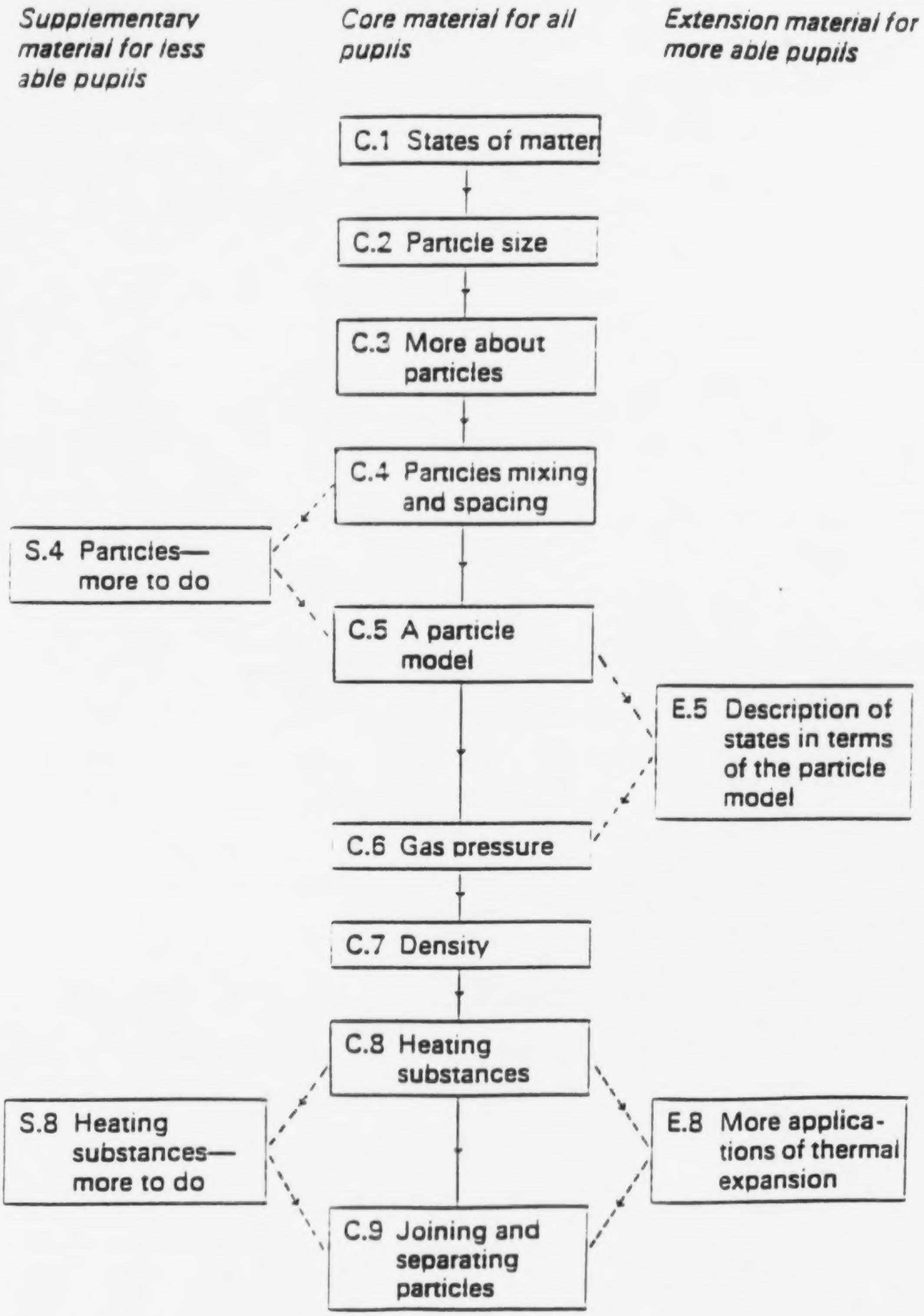
A similar approach is taken for lower secondary school, with contents specified at somewhat greater length and by fields rather than by grade levels. Clearly the major tasks of lesson construction and selection of appropriate instructional activities rests with the teachers in individual schools (Stigler & Stevenson, 1991), particularly since texts for elementary schools are quite brief, as are the accompanying teacher guides. Teachers do have other resources on which to draw, however. Each month magazines are published (by nongovernmental organizations) that provide grade-appropriate instructional examples for the subject matter taught in school; these magazines are very popular with teachers and are widely used by them in constructing their lessons.

Hong Kong. In contrast to Japan, Hong Kong publishes detailed syllabi for all grades in nine academic fields, in ethical/religious education, and for practical and technical subjects. The syllabus covering junior secondary education (grades 7-9) in science is 235 pages long, 3 pages of which are concerned with overall goals and notes on teaching (Curriculum Development Committee - Hong Kong, 1986). The syllabus discusses 15 content units (6, 6, and 3 for grades 7, 8, and 9, respectively) and gives time allocations for each unit and for total units per grade (112 periods per grade). Each unit is further subdivided into content subunits, with a flow chart provided to guide the teacher (see Figure 4-2 for an example). Learning objectives are given for the overall unit as well as for each subunit. Each subunit describes classroom activities in some detail and accompanies these with notes and diagrams for the teacher, as illustrated in the sidebar.

The syllabus suggests that students should be engaged in carrying out many of the activities themselves, and that questioning and class discussion should be part of the instructional process. Educational television programs are available for use with the syllabus (24 for each grade); the *Scottish Science Teachers' Guide* and *Nuffield Science Materials* are cited as providing further guidance to teachers.

Figure 4-2

Suggested flow diagram for teaching


Supplementary material for less able pupils
Core material for all pupils
Extension material for more able pupils
C.1 States of matter
C.2 Particle size
C.3 More about particles
C.4 Particles mixing and spacing
S.4 Particles—more to do
C.5 A particle model
E.5 Description of states in terms of the particle model
C.6 Gas pressure
C.7 Density
C.8 Heating substances
S.8 Heating substances—more to do
E.8 More applications of thermal expansion
C.9 Joining and separating particles

Suggested time allocation:
20 periods

"Unit 4: Matter as Particles

Subunit C.1: States of Matter

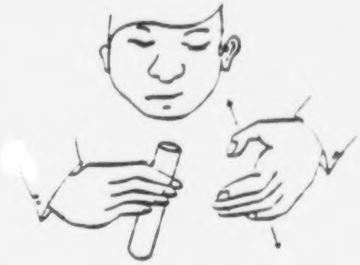
Expected outcomes

Pupils should be able to:

a) state that there are three states of matter

b) outline the properties of solids, liquids, and gases

Activities	*Notes*
	The teacher may revise C.3 of Unit 2 as an introduction to classifying matter.
1. Arrange the materials provided into solids, liquids and gases.	Materials may include wood, water, oil, brown gas (e.g., nitrogen (IV) oxide), rubber, coal gas, air and metal, etc.
2. Examine carefully the following materials: iron, rubber, plasticine, perspex, wood, stone, polystrene.	This activity leads to some of the common properties of solid.
Are all solids opaque?	No.
Are all solids heavy?	No.
Are all solids hard?	No.
Can solids change shape by themselves?	No.
How would you change the shape of a solid?	By pressing.
What properties do solids have in common?	Fixed volume and shape.
3. Measure the volume of a liquid (e.g., water, methylated spirit) using a measuring cylinder. Then pour the liquid from one container into another (e.g., from a test tube into a conical flask, from a conical flask into a beaker, etc.). Observe carefully. Finally pour it back into the measuring cylinder and find the volume.	This activity leads to some of the properties of liquids.
Are all liquids colorless?	No.
What happens when liquids are transferred from one container to another?	They take the shape of the containers.
Is there any change in volume?	No.
What properties do liquids have in common?	Fixed volume but no fixed shape.

Activities	*Notes*
4. Push an inverted beaker into water.	This activity is to detect the presence of air -- a gas.
5. Place a small amount of substance (e.g. ammonium carbonate or copper (II) nitrate) in a test tube. Heat gently and observe carefully.	*Caution:* 1) Do not use too much substance. 2) Do not place the nose directly above the test tube. 3) Avoid inhaling too much gas. The following diagram shows the correct way of smelling gases: 
Are all gases invisible?	No.
Are all gases odorless?	No.
What properties do gases have in common?	No fixed volume and shape.
6. Discuss the differences among solids, liquids and gases.	Class discussion should bring out the common properties of solids, liquids and gases. Solids have a fixed volume and shape. Liquids have a fixed volume but not a fixed shape. Gases do not have a fixed volume and shape. Solids stay put, liquids flow, and gases flow more readily."

(Curriculum Development Committee — Hong Kong, 1986.)

France. The curriculum guides for France are both brief and detailed. There are guides for the physical sciences and the biological and geological sciences for three grade level ranges: elementary school, grades 6-9, and grades 10-12. In addition there are guides outlining the whole educational program (including, in addition to the sciences, some ten other obligatory subjects and four or five optional subjects) for each specific grade. The guides give very brief and general guidance on methods and pedagogic approaches. For example, the 8th-grade guide notes that physics and chemistry are experimental sciences; therefore, instruction should stress acquisition of the experimental method (observation, investigation and control of variables, measurement, formulation of hypotheses, and experimentation to verify a hypothesis). Students should be active participants in appropriate experiences drawn from the natural or technological environment so that clear conclusions are possible.

On the other hand, the guides are very explicit and quite detailed about the subject matter to be covered. For any given subtopic, each concept or principle to be learned is given several paragraphs. The concept is stated at the outset and then elaborated with further factual information and explanatory material to illustrate its logical development in the course of instruction.

The subject matter content of the French curriculum is notably different from U.S. offerings in at least two ways. First, technology is part of the school curriculum; for example, in grade 8 this subject is to take two hours per week out of an obligatory 28 hours for all instruction; the physical sciences and the biological/geological sciences together are given three hours per week (1.5 hours each). The purpose is to engender an understanding of how technological artifacts, complex technological systems, and the organization of information are conceived, developed, tried out, and used. Students are expected to learn to appreciate how knowledge is mobilized and turned into action, and that both knowledge and its applications are always in flux and tied to the perspectives and values of society. At the same time, students are to acquire an understanding of the world of work and how it has been shaped by the evolution of technology. A second difference between the French and the U.S. science curriculum is the greater emphasis in French biology texts on human reproduction, including fertility, birth control, and diseases and their prevention.

England and Wales. Recently proposed reforms in science education for England and Wales (Department of Education and Science and the Welsh Office, 1991) focus the curriculum on five areas: scientific investigation, life and living processes, earth and environment, materials and their behavior, and energy and its effects. Each of these is further divided into three or four strands. The curricular areas are organized according to four developmental levels, with ages 7, 11, 14, and 16 as mark points. An alternative curriculum at the fourth level of development, intended for students interested in pursuing areas other than science, includes the same five major areas but with some strands omitted. For example, the strands for "energy and its effects" are energy and forces, electricity and magnetism, and light and sound. "Light and sound" is omitted from the alternative curriculum. Somewhat heavier emphasis is to be placed on the first content area, "scientific investigation," at the earlier developmental levels, with the knowledge and understanding of science embodied in the other four areas increasingly emphasized as students move through school.

The curriculum for each strand is formulated according to 10 "statements of attainment" which overlap the developmental levels. (Ranges of attainment applying to the four developmental stages are 1-3, 2-5, 3-7, and 4-10 for each of the five major areas.) The statements of attainment cited below are illustrative. They are two of the 10 for "life and living processes," which includes four strands: knowledge and understanding of the organization of living things and the processes which characterize their survival, the diversity and classification of life forms, including the causes of variation and the basic mechanisms of inheritance, selection and evolution, the factors affecting population size and human influences within ecosystems, and energy flows and cycles of matter within ecosystems.

"LEVEL 2

Pupils should:

a) know that living things need certain conditions to sustain life.

b) know that all humans are different from each other.

c) know that different kinds of living things are found in different localities.

d) be able to classify waste materials into those which decay naturally, those which can be recycled and those which have to be disposed of by other means."

"**LEVEL 7**

Pupils should:

a) understand how life processes enable organisms to survive in their environment.

b) understand the principles of a monohybrid cross involving dominant and recessive alleles.

c) understand the relationships between population growth and decline and environmental resources.

d) be able to interpret pyramids of numbers and biomass."

For the strands on population size and human influences within ecosystems and on energy flows and cycles of matter within ecosystems are eliminated, as are attainment statements c) and d) for both level 2 and 7.

The curriculum document provides considerable guidance on programs of study, including appropriate activities and instruction. The recommended programs of study stress starting with activities related to students' everyday experiences and increasing the complexity of the activities as instruction proceeds, promoting invention and creativity and leading students to an understanding of how science is done. Instructions on specific concepts to be studied and suggested activities are fairly brief and general.

There is an analogous curriculum guide covering technology (Department of Education and Science and the Welsh Office, 1990). The developmental stages and the statements of attainment are formulated in the same way, but more examples of activities are given, perhaps because the whole field is less familiar to teachers. Two major subjects are treated: (1) design and technology capability, subdivided into four attainment levels (identifying needs and opportunities, generating a design, planning and making, and evaluating), and (2) information technology capability. For the first area, the guide advises that, at each stage,

> pupils should design and make:
>
> a) artifacts (objects made by people);
>
> b) systems (sets of objects or activities which together perform a task); and
>
> c) environments (surroundings made, or developed, by people);
>
> in response to needs and opportunities identified by them.

> Contexts (situations in which design and technological activity take place) should include the home, school, recreation, community, business, and industry, beginning with those which are most familiar to pupils, and progressing to contexts which are less familiar.
>
> Pupils should be taught to draw on their knowledge and skills in other subjects, particularly the foundation subjects of science, mathematics, and art, to support their designing and making activities. . . . As pupils progress, they should be given more opportunities to identify their own tasks for activity, and should use their knowledge and skills to make products which are more complex, or satisfy more demanding needs. (Department of Education and Science and the Welsh Office, 1990).

4.3 Directions of Curricular Reform

The brief review in this chapter indicates that there is considerable consensus within the U.S. and among industrialized countries on the broad goals of science education:

- All students should acquire sufficient science knowledge and habits of mind to cope successfully with a multiplicity of science- and technology-linked problems that will confront them as individuals, as community members and citizens, and in the workplace.
- All students should acquire sufficient preparation in science to allow them, if they so wish, to pursue either further education in science or engineering or to move into a satisfying technology-linked occupation with advancement potential.
- All students should come to appreciate the power and influence of scientific inquiry and technological invention sufficiently to continue engagement with these fields throughout their lives.

There is consensus as well on many of the desired outcomes, although not always on the methods for reaching them:

- Students should understand some core science content in depth. Some reform recommendations and curriculum guides express this core knowledge in terms of the "big ideas" or central connecting themes that cut across the sciences and technology (as is true of several of the state frameworks). Sometimes the curriculum recommendations are centered on key concepts and understandings germane to each of the major fields of science and to technology. In either case, students should understand the connectedness of major ideas and concepts and distinguish between those that are fundamental and those that are peripheral.

- Students should understand that science is not a collection of facts but several organized bodies of knowledge that allow an understanding of natural phenomena and can be applied to solve human problems of adaptation. They should appreciate that the theories scientists create serve as tools for organizing and interpreting knowledge about the natural world, that these theories are evaluated by communities of scientists according to established criteria, and that this is a process of successive approximation. It is in this sense that scientific concepts are provisional and subject to revision.

- Students should be able to reason scientifically, which includes the ability to identify the crux of a problem, make conjectures, discriminate between observation and inference, decide on appropriate evidence and how to collect it, collect and analyze the evidence, judge the quality of the evidence and draw conclusions, communicate conclusions and the supporting evidence, and take appropriate action.

- Students should acquire the disposition to apply the science content knowledge and reasoning ability they have acquired to a variety of life situations in and out of school. This requires flexibility and the ability to draw on scientific ideas in multiple contexts.

- Students also should understand some of the limits and possibilities of science and technology. They should understand that both are human activities set in a historical context and are influenced by, as well as influence, the culture of which they are a part. In particular they should understand that scientific information can inform the design of technologies and can help estimate potential risks and benefits, but cannot yield decisions that entail value judgments.

The curriculum reforms and proposed reforms summarized in the preceding section address the *intended curriculum*: mandates on the amount of time to be spent on science, curriculum materials, curriculum standards and frameworks to guide instruction, and assessment mechanisms to gauge progress toward attaining desired outcomes. A second approach (sometimes combined with guidance on curriculum content) focuses on the reform of the *implemented curriculum*: the delivery of the curriculum in the classroom. Based on the last twenty years of research on how students learn science, several instructional principles have evolved that are thought to advance the goals of science education; they are common in reform documents:

- Students must be engaged in the learning process — they must be active participants in instructional activities. This entails their being able to perceive meaning in the instructional content that is of interest or importance to them, in contrast to perceiving science knowledge as arcane collections of disconnected facts that are of limited use.

- Phenomena are best understood if learned in context; concepts as well should likewise be presented in the context of concrete situations so that students can construct the abstract concept through the situation to which it applies (Brown, Collins, & Duguid, 1989). This principle of "situated" learning is one of the main reasons for arguing that students should engage with hands-on explorations and scientific investigations. If science knowledge is taught entirely as abstractions, students will either forget the knowledge, because it has little meaning for them, or misconstrue what they are learning.

- A second reason for engaging students with the "stuff" of the real world (the natural world or the designed world) is that the processes and content of science cannot be taught in isolation from each other. Science needs to be understood as a way of knowing, not just as a body of organized knowledge that helps explain and predict the world around us.

- A third reason for making scientific inquiry part of the curriculum is that modeling the activities that scientists carry out, at a developmentally appropriate level, will engender an understanding of science as a way of knowing. Doing so as part of a group helps illuminate the role of scientific discourse in the development of scientific knowledge.

- Classroom tasks should be designed to allow students to connect new substantive ideas to knowledge they already have. Hence, teachers must build bridges between curriculum content and students' current knowledge and skills, what they already understand or think about the phenomena, and the concepts being presented. The kinds of misunderstandings students are likely to form need to be anticipated; representations they are likely to understand and find interesting must be developed.

- For science learning to take place, instruction must bring about conceptual change. Driver, Guesne, & Tiberghien (1985) argue that students must have the opportunity to make their ideas explicit, must be confronted with discrepant information or events, must be led through Socratic questioning to generate a range of explanations for the discrepancies, and must have a chance to test the validity of their explanations in a range of situations.

- What is expected of students and why, as well as the criteria by which students' achievement and performance in science will be judged, should be communicated clearly to students, other teachers and administrators in the system, and parents.

4.4 The Implemented Curriculum

How closely does average classroom practice in the U.S. match the intended curriculum and instruction as reflected in current reform documents? In how many schools are these reforms in place? What are the gaps between current and "ideal" curricula in different types of schools? What curricula and instruction are experienced by different population groups in the U.S.? To answer such questions as these, one must ask some prior questions: What information is available on the curriculum as implemented in the classroom? And how good is that information? Individuals interested in following-up teachers who have participated in staff development and enhancement projects need to be aware of the limitations of the methods for doing so.

4.4.1 Methods for Documenting the Implemented Curriculum

Unfortunately there is an inescapable problem in collecting information about the implemented curriculum: methods that provide the most valid information are not feasible on a wide enough scale to allow generalizations to be made. For instance, direct classroom observation provides data on content coverage, use of curriculum materials, and instructional strategies employed. If the observations are accompanied by analyses of the textbook, activity guides, tests, and other curriculum materials most heavily relied on by the teacher, as well as samples of student work and interviews with students and teachers, a quite complete picture of the curriculum implemented in the observed classroom(s) will be obtained. (See, for example, the case studies on the state of science and mathematics education conducted by Stake and Easley, 1978). Clearly this case-study approach, while yielding rich information, is too intrusive, labor-intensive, and costly to carry out in very many classrooms, let alone in a sufficient number to allow one to generalize about the science curriculum and activities experienced by most U.S. students or any subgroup.

Surveys asking questions of teachers and students about curriculum content, emphasis, and activities in science lessons provide an alternative to in-depth studies. While questionnaires can be administered to large enough samples to yield generalizable information, they must be kept reasonably short so as not to impose too great a burden on respondents. This inhibits probing either curriculum use or instructional practice in depth. Furthermore, to get information relevant to specific subgroups (say, Hispanic girls in high school in the Southwest) compared to the population as a whole or to other subgroups, sample sizes have to be quite large, making the surveys very expensive. Additional problems with survey questionnaires are that items on content coverage, curriculum emphasis, and pedagogic strategies may each require respondents to remember back over the entire school year, exercise judgments that are difficult to make, and report on their own behaviors and attitudes.

Knowing about Content Coverage and Curriculum Emphasis. Questions on topic coverage have been asked in several different ways in various surveys; each way creates different problems. One approach is to list a set of topics commonly found in a course and to ask the teacher whether these topics were covered and the nature of the coverage. For example, in one of its surveys of teachers, the National Education Longitudinal Study of 1988 asked biology, chemistry, and physics teachers whether and how they had covered a given set of topics — intended to represent the curriculum — in each of their classes. The topics for biology teachers were cell structure and function, genetics, diversity of life, metabolism and regulation of the organism, reproduction and development of the organism, human biology, evolution, and ecology. (Similar sets of discipline-specific topics were provided to physics and chemistry teachers.) For each of these topics, teachers were asked to check one of the following responses:

1) No, topic is beyond the scope of this course.
2) No, but I will teach or review it later this year.
3) Yes, I taught it as new content.
4) Yes, but I reviewed it only.
5) No, but it was taught previously.

This set of responses requires several problematical tasks of the respondent that may be handled differently by different individuals. First, the teachers have to judge how subtopics that they have taught fit into the rather broad topic categories to which they have to respond. Second, there is no differentiation with respect to length of time given to a topic, so that answer (3), for example, may indicate quite different coverage for different respondents. Third, answers (2) and (5) are likely to be conjectural rather than factual, since teachers in most U.S schools cannot know for certain what another teacher covered earlier or how they may have to adjust their future lesson plans. And fourth, the distinction between (3) and (4) may be fuzzy (and made differently by different respondents), since treatment of many topics would involve both review and new material.

Another approach has been used by the International Association for the Evaluation of Educational Achievement. In the Second International Science Study, conducted in 1983-86, teachers were asked — for each question on the student test — whether the students in their class had (or would have) the opportunity to learn the concepts tested by the question

1) during a previous year's science course.
2) during this year's science course,
3) in a future science course,
4) in no part of the science program.

While this approach tied content coverage questions to very specific subject matter, it required the teacher to reconstruct what concepts the student might need to use to answer a particular item — again, a response that could easily have been constructed quite differently by different teachers for any given item. The method is also dependent on the content covered by the test, which may not necessarily be representative of the content taught by the teacher or the emphasis given to various topics.

Attempts have been made to get information on depth of treatment of topics as well as coverage by asking teachers to rate the emphasis they give in their classes to each topic on a list, using a Likert or similar scale, or to estimate the amount of time (or class periods) spent on a topic. Both methods rely on the teacher's memory. The first method is likely to be quite unreliable from person to person unless some definitions are given, usually in terms of time ranges (in which case it comes to resemble the second method). The second method can be quite burdensome for the respondent, it forces a false disaggregation of time spent on topics that may have (or should have been) taught together, and it is likely to lend the data an aura of precision that they do not have.

Work is going on currently to achieve a compromise between methods that yield valid information on very few classrooms and inaccurate, large-scale survey methods. This work will explore the possibility of anchoring the survey information through selective in-depth probes, such as analyzing selected curriculum materials and student work, periodic classroom observations. and analysis of teacher diaries that log their activities in some detail (McDonnell & Burstein, 1991). Its purpose is to validate the survey information collected on large samples of teachers and classrooms by checking the results with a few instances of more comprehensive portrayals of curriculum and classroom practice.

Knowing about Instructional Practices. The reforms aimed at improving science education emphasize that science content and science instruction cannot be considered in isolation from each other, that together they make up the curriculum as students experience it. Therefore, considerable effort has been expended on documenting teachers' instructional practices in science. The methods are analogous to those used to establish content coverage and emphasis, since studies — whether small-scale and intensive or large-scale surveys — usually try to collect information on both content and instruction. The problems noted above with using survey information to establish content coverage and emphasis are aggravated, however, when using such information to shed light on teachers' instructional practices. Issues of interpretation (both by the teacher in responding to the questionnaire and by the researcher in analyzing the responses) loom larger: What is "classroom discussion"? What does "demonstration of a scientific principle" mean? What is "student project work"? What do answers about "use of student groups" mean when one does not know the nature of the groups or what they are doing in science class? What kinds of problems do teachers have in mind when they say they "emphasize problem-solving skills"? Moreover, such questions are open to corrupt answers insofar as teachers familiar with some of the tenets of exemplary practice may believe they are following them in the classroom when, in fact, they are unable or unprepared to do so to the extent that they believe they are.

Discrepancies in perceptions, at least between students and teachers, show up in the report of the 1990 NAEP science assessment (Jones, Mullis, Raizen, Weiss, & Weston, 1992). For example, 48 percent of eighth grade students said that their teachers never asked them to write up a science experiment, whereas the teachers of only 7 percent of the students gave this answer; 21 percent of the students said they never did science experiments in class, compared with 4 percent of their teachers who made this response; half the students said they never gave oral or written science reports, compared with 14 percent of their teachers who reported they did not assign such work.

One might conjecture that the teachers' interpretations of the questions' meanings were closer to the mark than those of the students, but evidence on this point is lacking. Nor can this explain the discrepancies between hours of homework assigned, as reported by teachers, and hours of homework done, as reported by students: 20 percent of the eighth grade students reported doing no science homework, whereas the teachers of only 1 percent of the students reported assigning none; 41 percent of the students reported spending one-half hour per week, whereas the teachers of only 10 percent of the students reported assigning this amount; 16 percent of the students reported doing two or more hours of science homework per week, whereas the teachers of 57 percent of the students reported assigning that amount. Perhaps teachers assign more homework than students are willing to do; perhaps teachers overestimate the amount of time it will take students to do the assigned work. Again, further evidence is lacking, and one is left to wonder about the meaning of these data specifically and information that relies on self-reporting in general.

4.4.2 The Implemented Curriculum — How Close to the Intended Curriculum?

Despite the problems of obtaining accurate and generalizable portrayals of curriculum and instruction as students actually experience it, the bulk of the evidence continues to point to two general conclusions:

- Little has changed in most science classrooms in terms of implementing current reform recommendations.
- This is particularly true in schools serving populations currently underrepresented in the sciences, thus undermining the goal of science for *all* students.

Perhaps this is not surprising, given the skepticism of teachers regarding current reform efforts. Half the teachers surveyed in 1987 by the Carnegie Foundation for the Advancement of Teaching (1988) were not convinced that these efforts would help them in the classroom. They gave the reform movement a grade of C; moreover, nearly 60 percent thought that morale was worse in 1987 than in 1983.

Little Change. As with the teaching of other subjects, science teaching has long been dominated by textbooks, teacher lectures, workbook exercises, and writing answers to routine questions and problem sets (Goodlad, 1984). The dominant orientation is an emphasis on topics, not concepts; the dominant teaching model assumes that learning occurs through listening and reading. Current data reconfirm these findings. The 1990 NAEP science assessment reported that 97 percent of eighth grade students had teachers who emphasized science facts and terminology; about one-fourth of the students attended classes that placed little or no emphasis on laboratory skills or understanding the nature of science as a discipline (Jones, Mullis, et al., 1992). The NAEP data also bear out the general finding that novices and experienced teachers alike rely most of the time on two limited teaching techniques — telling and the assignment of seatwork exercises. The most commonly used instructional techniques reported by eighth grade teachers were discussion, lecture, teacher demonstration, and students reading about science. Quite similar practices were reported for 1977 and 1985-86 (Weiss, 1987). Although teachers and principals believe that hands-on approaches should be used, less than a third of class time is devoted to this approach in the elementary grades; lecture and discussion dominate three-quarters of the time in grades K-3 and almost 90 percent in grades 4-6. The difficulties in obtaining the requisite materials and equipment and managing the students using them are cited by teachers and principals as barriers to hands-on and investigative science in the elementary school classroom (St. John, 1987). Thus, instruction as it is carried out in most elementary schools primarily involves direct transmission of information to students.

This appears to be true at the secondary level as well, even when science experiments are part of the curriculum. Although between half to three-quarters of the students enrolled in high school science classes in 1986 reported doing laboratory work, most of this work was highly structured through written laboratory guides and/or instructions by the teacher (Jacobson & Doran, 1991). Only 5 percent of these students reported making up their own problems and methods. Surprisingly, one-quarter of twelfth-graders taking science in 1990 (presumably mostly advanced courses) reported that they never did science experiments in class, and one-third reported that their teachers never asked them to write up a science laboratory experiment (Jones, et al., 1992).

Curriculum and Instruction for Minorities and Females. Students of whom teachers have low expectations in science — girls, students coming from low socioeconomic backgrounds, African-American students, and Hispanic students — are likely to get watered-down curriculum content as well as watered-down instruction (Oakes, 1990). Table 4-2 indicates the kinds of disparities that arise in curriculum content through tracking of students, presumably on the basis of ability. The figure is for mathematics; similar tracking occurs in science, although differences in course content are not as well documented. The effects become clear in high school in terms of student enrollments in different types of science courses. The problem is that tracking starts early in elementary school. Students usually are assigned to different classes by ability and, within a given class, they are assigned to ability groups for reading and mathematics. Children seldom move from low-ability tracks to tracks at higher ability levels. Though the criteria for tracking are presumed to be based on ability, minority

Table 4-2

Median Anticipated Number of Periods for Selected Topics for Eighth Grade Classes by Class Type: U.S., 1981-1982

	Median number of periods				
Topic	All classes	Remedial	Typical	Enriched	Algebra
Common fractions	15	20	20	10	2
Decimal fractions	15	20	15	10	1
Ratio and proportion	10	10	10	6	4
Percentage	15	15	15	10	2
Measurement	10	10	12	10	1
Geometry	15	10	15	15	1
Formulae/Equations	20	2	20	26	50
Integers	10	10	15	10	8
Probability and statistics	4	0	5	5	0
Number of classes	236	24	155	26	31

From: International Association for the Evaluation of Educational Achievement (1985) students and poor students are disproportionately placed in lower tracks, receive a "thin" curriculum in science, and end up enrolling in low-level science and mathematics classes. Thus, they miss the richer curriculum that characterizes high-track classes, where teachers spend more time on instruction and assign more homework, and students have greater access to science-related resources (Kahle, Matyas, & Cho, 1985). These disparities continue for minorities. Although females have increased their enrollments in higher-level science and mathematics courses in the last decade, blacks and Hispanics have not done so to the same extent. For example, considering the population as a whole, nearly two-thirds (an equal percentage of males and females) had taken six or more semesters of mathematics in high school, but only 46 percent of blacks and 54 percent of Hispanics had done so (Mullis, Dossey, Owen, & Phillips, 1991).

That teacher expectations in mathematics and science are higher for boys than for girls is well documented (Oakes, 1990), and these expectations affect achievement.[3] Indeed, in IEA's second international study of science achievement, the U.S. exhibited considerable male-female differences (favoring the males) in science achievement for all grades and subjects tested. The differences were greater for the U.S. than for most of the participating countries (Jacobson & Doran, 1991). In grade 5 the U.S. exhibited greater differences between male and female students' scores than all but three other countries out of 15; in grade 9 the U.S. ranked 13th highest in male-female differences out of 17 countries.

Instructional treatment differs even within the same class, in accord with teacher expectations. Students considered less able are called on less often, asked lower-level questions, given less time for answers, and given fewer hints (Oakes, 1990). There also is evidence of differential access to science instruments, computers, and other resources between males and females. As long as attitudes prevail that relate ability in science to sex, race, ethnicity, or socioeconomic status, and as long as curriculum and instructional practices systematically place certain student groups at a disadvantage, the goal of scientific literacy for all students will elude the U.S.

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[3] *Teachers only reflect general societal attitudes. Stevenson, Lee, and Stigler (1986) have demonstrated the strongly held belief among U.S. students and parents that ability is the main determinant of success in science and mathematics performance, whereas Chinese and Japanese students and parents place greater value on effort.*

4.4.3 Is Help on the Way?

This section describes briefly some major federal programs designed to help implement current reform recommendations and curricula in schools. The largest such program is the U.S. Department of Education's Eisenhower Mathematics and Science Education States Grants Program, currently operating at about $300 million per year. This program provides funds on a formula basis to states, local districts, and institutions of higher education to improve the skills of teachers and the quality of instruction in mathematics and science. All states and approximately 85 percent of the nation's school districts receive funds under this program. Because most of the funds go to local districts, there is considerable flexibility in how moneys are used to enhance teachers' skills and implement reform. An evaluation of the program found that, in the 1988-89 school year, over 600,000 teachers participated in experiences funded through this program, ranging from support for attending a professional meeting (for example, an NSTA annual or regional meeting) to workshop training with follow-up to implement a specific reform curriculum. In addition to the state program, the Eisenhower program has a national component, which funds competitively awarded grants to develop curriculum frameworks, implement innovative curricula in schools, and develop alternative teacher certification routes for individuals with science or mathematics backgrounds.

The National Science Foundation also invests considerable funds in teacher development, amounting to $100 million in 1992. The projects supported represent a balance of short-term and more intensive interventions, ranging from courses offered for advanced credit to workshops with follow-up during the academic year to attendance at conferences. Some of the projects are aimed at individual teachers, others, at teacher leaders expected to promote improved science teaching in their home districts. Still others work with teams of teachers and administrators to help them plan and institute changes in their schools' science instruction. The National Science Foundation also supports projects intended to reform the pre-service education of teachers and the development of materials to serve this purpose. Program objectives include attracting individuals of high ability into mathematics and science teaching as well as expanding the science content and pedagogical techniques of courses offered to future teachers. The Foundation has estimated that, in 1992, their teacher preparation and enhancement programs reached 20,000 teachers directly and 200,000 teachers through multiplier effects built into many of the projects.

The U.S. Department of Energy (DOE) invests some $25 million of central funds in precollege activities, mostly carried out through the DOE National Laboratories, which add considerable resources of their own (usually through staff time) to the precollege funds they receive from central DOE sources. Most of these funds are invested in teacher development activities. One program operating across the DOE Laboratories offers eight-week research opportunities for teachers, which allow them to work on leading-edge science and technology research projects with DOE scientists and also develop teaching materials and strategies based on their research to take back to the classroom. Every year, over 200 teachers participate in this intensive program. The Laboratories also offer a variety of teacher enhancement opportunities, ranging from training in a particular curriculum to sending scientists to the schools once a week throughout the school year to help with the science curriculum. Some of the Laboratories have formed partnerships with rural or urban school systems to assist them in implementing long-term improvement in science and mathematics education. For example, a partnership has been created among the four Laboratories and several colleges and universities in the San Francisco Bay Area to prepare the nearly 3,000 teachers in the Oakland Unified School District to implement the new California curriculum frameworks in science and mathematics.

A program attracting great interest is the NSF's Statewide Systemic Initiative (SSI) for reforming mathematics and science education. Each state interested in competing must demonstrate in its project proposal the collaboration of the governor and his executive offices, the legislature, the state department of education and regional and local education authorities, institutions of higher education, business, and public leaders. Although they can focus on an area of particular need in a state, projects must be designed to address the various elements critical to implementing and institutionalizing improvements: organizational structures and decision making in education; provision and allocation of resources; recruitment, education, and professional development of teachers and other staff; curriculum goals and content; nature and delivery of instruction, including the use of technology; and facilities and equipment. Each project must include an evaluation component; the NSF will evaluate the overall program as well. Through 1992, 21 states have received SSI awards, each intended to provide support for five years; another cycle of awards takes place in 1993, to be made to an additional five to ten states. The Foundation plans to initiate in the near future an urban systemic initiative program modeled on the state program.

A heartening development is the creation of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET, 1991). Through this mechanism, the federal government intends to coordinate its education activities to greater effect so as to speed the pace of reform. Two other encouraging developments are a memorandum of agreement between the NSF and the U.S. Department of Education intended to coordinate the science and mathematics education reform efforts of these two agencies, and the creation of the Eisenhower National Clearinghouse, which is to make reform curricula widely available through an associated network of ten regional consortia. Readers of this book may be well advised to keep abreast of these investments in science and mathematics education reform being made at the federal level so as to build on them in whatever ways appear to be feasible and productive for their own projects.

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5. IN-SERVICE EDUCATION MODELS FOR ENHANCING THE TEACHING OF SCIENCE

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5.1 Introduction

Key issues addressed by the science education reform movement include the purposes of science education, the context for the science curriculum, the scientific subject matter most worth knowing, and the conditions that foster that knowing (e.g., Hurd, 1986). The purpose of doing science is to make sense of the world. Guided hands-on laboratory experiences are being adopted as integral to science instruction in order to ensure that science teaching and learning parallel the methods of investigation used by scientists to understand the natural world (Raizen, Baron, Champagne, Haertel, Mullis, & Oakes, 1989). Student investigations of phenomena (as opposed to textbook presentations) are the backbone of the new curriculum, and the focus of these investigations is the development and use of science inquiry or process skills — predicting, hypothesizing, observing, recording data, making inferences and generalizations — to solve everyday problems.

The assumption underlying this approach is that meaningful, conceptual understanding and interest in science develops through engaging students in doing science. Doing science requires not only science, but also mathematics, reading, and writing — in other words, an integrated curriculum. The primary instructional tool is the provision of multiple, guided experiences which challenge groups of students working together to question, hypothesize, test, and debate their ideas about science and scientific phenomena. In this way, students are afforded the opportunity to reconcile the differences between their experience-based theories of the world and their experiences in the classroom.

Science education reform has implications for teacher enhancement with respect to the teacher's role and the physical and social organization of the classroom. To teach in a manner consistent with reform, teachers will require a firm grasp of the subject matter so that they can encourage and support an inquiry approach in which students ask questions and generate solutions. Teachers will need to view their role in the classroom as one of a facilitator as opposed to a conveyor of knowledge. And teachers will need skills in management of the physical and social organization of the classroom required for small-group problem solving with concrete materials.

5.1.1 Guiding Assumptions

Teachers cannot be expected to immediately implement the reform agenda in their classrooms. They need to "own" the reform agenda, to acquire the knowledge and skills needed to teach in a manner consistent with that agenda. In-service education, then, plays a major role in reform. Indeed, in-service education should serve as a model for the teaching and learning that is expected to take place when teachers return to their classrooms. It should provide teachers with the opportunity to construct both content and pedagogical knowledge, practice the application of this knowledge, and take responsibility for knowledge construction and application. Our review of in-service science education programs, then, is guided by a set of assumptions underlying this perspective.

First, we assume that, to enhance the capabilities of science teachers, *teacher thinking* is central — we need to change the way teachers think about teaching science. The thoughts that teachers have and the decisions they make are related in their classroom performance (e.g., Clark & Peterson, 1986). This assumption contrasts sharply with many past efforts that attended primarily to changing specific teaching actions.

Of importance to teacher thinking is the recognition that teachers bring to their work a detailed and integrated understanding of students, curricula, classroom settings, and teaching methods — a *mental map* built on practical experience over time. These mental maps enable teachers to make sense of their classroom experiences. They enable teachers to classify events into categories and respond to them by drawing on a wealth of experience with similar events in that category. Mental maps also include pictures or typical *scenes* of the classroom and its inhabitants, which enable teachers to anticipate behavior typically occurring in those scenes. Moreover, these maps include well-scripted sequences of actions for teaching science that are consistent over time and that establish expectations for students. Finally, these mental maps are value laden. They represent beliefs about teaching and have a right-wrong, or ought-ought not quality which serves as the foundation on which teachers' motivation or desire to engage in a selected teaching practice is built. Teachers use these mental maps to interpret what is happening in the classroom, make decisions, and alter instruction (e.g., Clark & Peterson, 1986;

Shavelson & Stern, 1981). In-service education, then, must seek to alter these mental maps in a manner consistent with reform.

Our second assumption is that, although teacher thinking is a credible target for teacher enhancement programs, focus on actual *teaching actions* that occur in classrooms is equally important. Too often, desired change is considered to have occurred when teachers give some evidence that they understand a particular recommendation that was the objective of an enhancement activity, or when they report a willingness or even a desire to adopt the recommendation in their teaching. Teacher educators observing these indicators of understanding and motivation during training are tempted to claim that the teacher enhancement program was effective. Although such short-term changes may be necessary, they alone are not sufficient but must be accompanied by changes in teachers' actions in the classroom. One important implication of this assumption is that in-service education should include extensive hands-on activities for teachers to practice skills.

Our third assumption is that differences between learning by adults and by children exist which have particular ramifications for the planning of enhancement programs for teachers. Adults have status, responsibilities to others, a larger and usually richer body of experience, different motives and learning needs, and even a time scale that is different from children (Titmus, 1989). Moreover, the adult's self-concept seeks self-direction rather than other-direction in learning (Knowles, 1981). Adults, who have generally acquired a much larger experiential base than children, tend to define themselves by that experience rather than by external sources, as children do. We therefore assume that a key characteristic of teachers, like other adult learners, is the desire and capability to exercise considerable direction and control over their own learning. In-service education, then, should allow teachers to regulate their own learning experiences (i.e., to assume a high level of learner autonomy).

5.1.2 Perspectives on Teacher Enhancement

Teacher enhancement programs range from single, one-hour encounters to lengthy summer institutes and even multi-year endeavors that link learning opportunities with ongoing support services. Such programs are offered at school sites, institutes of higher education, hotels, or even national parks, and remote, exotic "retreat" locations. It is clear from descriptions of these programs that teacher enhancement is "far from an exact science, nor can observers, users, or researchers come to grips with all the variables in any exact way"

(Kreitlow, 1990, p. 7). "There is not one program that is the best. There are only programs that are different" (Hentschel, cited in Kreitlow, 1990, p. 7).

Program variation can be captured from two perspectives. The first perspective presents five separate approaches for delivering teacher enhancement. Based on the work of Sparks and Loucks-Horsley (1990), this perspective distinguishes these approaches by the assumptions and theoretical/research underpinnings on which each is based. The second perspective presents three sets of design components. These components appear to be common to most teacher enhancement programs, though they vary substantially in the manner in which they are implemented across programs. The intersection of these two perspectives offers the teacher educator a detailed but functional conceptualization of teacher enhancement. Table 5-1 depicts the relationship of these two perspectives and contains references to teacher enhancement programs that illustrate these relationships. The field of practice, from which these illustrations came, often does not permit a faithful or exact implementation of any one approach and its ideal components. The examination presented below, informed as it is by these two perspectives, does not propose an "ideal model" of teacher enhancement. Rather, it offers a set of conceptual tools that we believe will be useful as teacher educators and their client teachers plan, implement, and evaluate enhancement programs appropriate for their specific and particular needs.

5.1.3 Approaches to Teacher Enhancement

Sparks and Loucks-Horsley's five "models" of staff development do not constitute separate, discrete models of intervention. Rather they appear to represent *approaches* or sets of programmatic activities which can be combined in varying ways as teacher enhancement programs are designed. These approaches include *training* in knowledge or skills, *observation and assessment* of teaching, *development and/or improvement* of curriculum, *inquiry* into teaching practice, and *individually guided* enhancement.

Table 5-1

Examples of Teacher In-Service Programs Arrayed by Five Approaches and Eight Key Components

Components of in-service programs	Approaches to In-Service Education				
	Training	Observation and assessment	Development and improvement	Inquiry	Individual guidance
	Preparation				
Planning	• U of Houston - Clear Lake		• East Tennessee State Univ. • U of Wisconsin, River Falls	• U of Houston - Clear Lake	
Forward-looking evaluation					
	Implementation				
Source of content	• EQUALS in Computer Technology • U of Houston - Clear Lake			• U of Houston - Clear Lake	• Mountain View Teacher Center
Delivery of content	• Project SEED • New Mexico Dept. of Education		• U of Wisconsin, River Falls		
Formative evaluation	• Gayford's Biotechnology Project				
	Follow-Up				
Coaching	• Project SEED				• Mountain View Teacher Center
Support	• Project Catalyst • ENLIST Micros • Cycle 22			• Education Technology Center	
Summative evaluation	• Harvard Project Physics • Berea City School District		• Santa Barbara Instructional Technology Project		

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5.1.4 Training Approach

In the minds of many educators, teacher training is synonymous with teacher enhancement, a very limited view, as this section will show. The training approach presumes the existence of knowledge, teaching behaviors, and instructional techniques that would be worthwhile for teachers to acquire and use in their classrooms. Typically teachers are provided with a carefully planned set of learning activities. These activities address a specific, clear set of outcomes which may include awareness, knowledge, and skill development as well as attitude change.

Whether the trainer is an outside authority or a peer teacher, he or she is normally assumed to be an expert in the training's content. The trainer assumes much of the responsibility for selecting and conducting activities intended to move participating teachers toward achievement of the specified outcomes. The value of such training content is often warranted by reference to a "research knowledge base" which is presumed to establish its effectiveness.

One example of a program that is built primarily on the training approach is the summer institute offered as part of Project Catalyst (Carlson, 1990). This three-year project allocates 75 percent of its efforts toward enhancing teachers' knowledge and understanding of major concepts in earth/space science, with a special emphasis on geology, astronomy, meteorology, and oceanography. Content is primarily delivered by college science faculty and outside consultants, although the project also offers teacher participants the opportunity to present content to each other. The summer institute, organized as a five-week, full-day program, incorporates a mixture of lectures, discussions, laboratories, and teacher presentations. The program was planned by university faculty and staff and offered to interested teachers in the region served by the university.

Teacher enhancement programs based on this training approach are not always consistent with our three guiding assumptions. Traditionally, for example, they tend not to provide teachers with the opportunity to interact with the content (i.e., to act on what they are learning), or to practice application in realistic settings (although in a few of these programs hands-on components have been incorporated). Teachers may have limited opportunity to govern their own learning.

A modified version of the training approach, one more consistent with our assumptions, is Project SEED (Science for Early Education Development). Planned jointly by the Pasadena (California) Unified School District and the California Institute of Technology, this program (Marsh & Sevilla, 1991) is currently training an entire district's elementary school teaching staff in the use of "hands-on" science teaching techniques. The training approach requires teachers to build familiarity with science content and teaching processes by working directly with curriculum kits that they use in their classrooms. Content is introduced by both experienced mentor teachers and scientists who, instead of delivering lectures or demonstrations, work with teachers as they use the kits.

5.1.5 Observation and Assessment Approach

To benefit from experience, teachers need focused feedback about their classroom performance, with deliberate examination of underlying premises and observed actions (Schön, 1987; Copeland, 1981; Glickman, 1990; Joyce & Showers, 1982). This examination involves purposeful conversations between the teacher and an expert trained in observation and coaching techniques. The observation and assessment approach is predicated on the assumption that professional change objectives benefit from direct feedback, enabling teachers to identify problems and implement corrections and reinforcing successful performance by reflecting its presence.

This observation and assessment approach may combine all three of our initial assumptions — changing teachers' thinking about teaching, putting new conceptions into action, and providing teachers an opportunity to shape their learning. The observer/coach assists the teacher in this process.

Joyce and Showers (1982) maintain that such a coaching process offers the recipient teacher a number of advantages. First, such observation provides companionship and moral support as the teacher and coach engage in mutual reflection, checking of perceptions, and sharing of success and frustrations. The teacher receives specific technical feedback intended to help review and modify his or her own teaching actions and grow in professional competency. Also, by providing an external perspective, the coach can assist the teacher in learning to "read" and understand student patterns of action and to plan accordingly.

5.1.6 Development and Improvement Approach

Teacher educators have long recognized the substantial learning that occurs as teachers develop and implement new curricula or instructional practices. Perhaps the most valuable product of a teacher-staffed materials development project is not the materials produced but the professional growth that occurs.

This approach creates a "need to know" in teachers by identifying a local need that can be addressed by developing curriculum materials or instructional practices. Teachers engaged in materials development clearly target their own pupils and, in so doing, define the course of the development project to meet their own particular needs. Hence this approach fits closely with our assumption that teacher enhancement programs should provide teachers with autonomy and the opportunity to define the direction of their work.

A graduate level course in Science and Technology designed for enhancement of in-service elementary and secondary school science teachers made primary use of the development and improvement approach (Rhoton & Pafford, 1990). The content of the course related to the interactions of science, technology, and society. A major goal of the course was to assist the participants in the integration of these issues into the curriculum. In this program, the "need to know" emerged out of extensive conversations between staff developers and teachers, the latter of whom concluded that currently available textbooks did not provide adequate coverage of science and technology issues. Of special concern to the teachers was the lack of materials related to local concerns with which their students were familiar.

After receiving materials and reading assignments and participating in introductory workshop experiences, the teachers turned their attention to developing sets of learning experiences for their students. For example, the geological strata in Northeastern Tennessee were identified as having a potentially high radon risk. The teachers developed several learning activities which not only taught students about the radon issue but also involved them in actual investigations, including field data collection, interpretation of results, and communication of findings among the several schools whose teachers were participants in the program.

5.1.7 Inquiry Approach

Most teachers confront difficulties every day and ask themselves what changes they might make to help them overcome these difficulties. Although these deliberations are typically undertaken privately and individually, some teacher educators have formulated processes by which they can be made purposeful and public and can benefit from collaboration between teachers and "research teams" including other teachers, educational researchers, and perhaps even research assistants. This approach uses the unique contributions that teachers can make to inquiry by involving them directly in formulating research questions which have relevance to their work and in collecting and analyzing data bearing on these questions.

Recall that the development and improvement approach aims at curriculum or materials development and tends to produce a tangible product (e.g., a curriculum guide or learner materials). In contrast, the inquiry approach casts teachers in the role of "scholars" and "innovators" (Zeichner, 1983) looking for answers to more basic questions of teaching and learning, such as uncovering relationships between patterns of teaching behavior and student involvement, exploring effects of pupil "helping" behaviors on other pupils' learning, and attempting to understand what appear to be gender or ethnic differences in performance.

The inquiry approach assumes that teachers have the ability to "formulate valid questions about their own practice and to pursue objective answers to those questions" (Sparks & Loucks-Horsley, 1990, p. 243). Thus it is quite sensitive to the need for self-directed and autonomous learning behavior in teachers. Furthermore, in helping teachers to examine critically their own teaching, the inquiry approach focuses on the thinking that lies behind teacher action as well as the actions themselves.

An example of the inquiry approach was added to the second year of the two-year program offered by the University of Houston-Clear Lake. During the first year, a training approach was used with 50 experienced teachers. They were instructed to use one or more cooperative learning techniques to teach the science curriculum in their classrooms. As the program progressed, the participating teachers voiced "numerous and significant reservations that the use of small cooperative groups for learning activities and the use of group praise as a reward would insure improved test scores for all students in their classes. In addition, the idea of using team scores and improvement scores was difficult to implement and integrate into traditional evaluation schemes" (Jones & Steinbrink, 1989, p. 544).

The program's solution was to initiate an inquiry approach in year 2, teaming participating teachers and researchers to test several potential solutions to the difficulties encountered with cooperative groups. The solutions were numerous but included adding a cooperative test review component, eliminating the team test score, and improving score calculations. The potential solutions were tested by the teachers comparing year 1 and 2 cooperative groups on student knowledge and skills, reading time, and attitudes toward cooperative learning and toward themselves as learners. In this revised program, then, teachers were fully integrated members of the research team, taking a direct role in defining the initial problem, posing tentative solutions, and testing answers using their own classrooms as research sites.

5.1.8 Individually Guided Approach

This approach, strongly based on our assumption of teacher autonomy, views teachers as the best authorities on their own educational needs and the ways by which these needs might be met. Teachers, in cooperation with staff developers, identify their own needs or professional interests, and together they develop a plan to meet those needs. The plan incorporates learning activities that may involve individual work or participation in activities with others who share similar needs and interests. The activities might be highly social and participatory, or they might be restricted to individual reading and library research. Whatever the types of learning activities used, the central characteristic is that they are requested and initiated by the teacher.

Perhaps one of the most prominent applications of the individually guided approach were the "Teacher Resource Centers." As described by Bell and Peightel (1976), these centers, which numbered over 600 in the nation in the mid 1970s, presented conditions in which individual educators could pursue their own professional development needs. Some centers were actual buildings where teachers met. Others were brokerage agencies that brought teachers together with those services that they required. They "allowed participants to share human and materials resources, to receive individualized and group assistance in a nonthreatening environment, and to make professional improvement at the participant's own rate and on the participant's own terms" (Bell & Peightel, 1976, p. 17).

As an example, the Mountain View Center for Environmental Education at the University of Colorado was structured to allow teachers to interact with individual staff members as they identified, gathered, and adapted material from the environment for their own classroom use. The direction that the teachers would take in their materials development activities and the resources they would access via the Center were entirely up to the teachers. Occasional group sessions were scheduled by Center staff when teachers' professional needs converged, but the individual teacher remained the primary focus of the Center.

5.1.9 Components of Teacher Enhancement Programs

In our examination of program descriptions, three sets of common design components emerged. The first set, which we label "Program Preparation," includes both initial planning and forward-looking evaluation activities intended to inform the program's preparation. The second set of design components, which we call "Implementation," includes consideration of the source of the content on which the in-service activity is based, the delivery of that content, and formative evaluation activities for making appropriate "mid-course corrections" of the program as it proceeds. The third set we call "Follow-up," it includes coaching and support components as well as final or summative evaluation activities for describing the degree to which the in-service program achieved its intended goals. Taken together, these three sets of design components offer a cluster of reasonable considerations that developers might address in designing and implementing in-service programs for science teachers.

5.1.10 Program Preparation

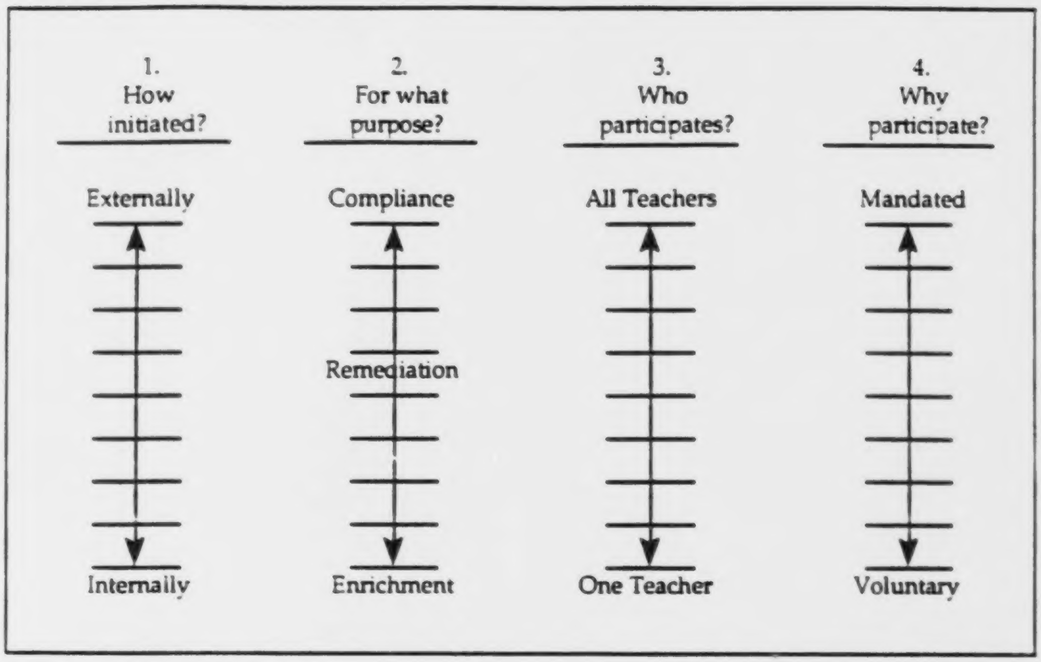
In preparing a teacher enhancement program, both planning and evaluation are critical. Planning generally focuses on program logistics (e.g., who attends? what personnel, supplies, and facilities are needed?). But planning must also include consideration of the organizational dynamics in which the in-service program will function and in which teachers work. Evaluation is normally thought of as occurring after the program has been implemented, but evaluation is central to all stages of a teacher enhancement program. At the preparation stage, "forward-looking" evaluation helps developers anticipate the potential success, worth, and merit of a program. We offer here a set of considerations for both planning and evaluation — considerations of the organizational setting in which the goals of the teacher enhancement program will be pursued, and of the need to engage planners in evaluation activities at the very outset of their planning process.

5.1.11 Planning

"Staff development is much more than the simple provision of a service to a single teacher or group of teachers. It also includes the organizational dynamics of schooling, such as school climate, the structure of authority, the norms that define relationships among school personnel, the nature of communications within a school or district, and the roles and responsibilities of the various personnel who belong to the organization" (Fenstermacher and Berliner, 1983, p. 5). Consequently, when planning a teacher enhancement program, questions regarding four important features of the proposed program's organizational setting need to be considered (see Figure 5-1).

Figure 5-1

Profile of a Staff Development Activity
(after Fenstermacher & Berliner, 1983)


1.
How initiated?
Externally
Internally
2.
For what purpose?
Compliance
Remediation
Enrichment
3.
Who participates?
All Teachers
One Teacher
4.
Why participate?
Mandated
Voluntary

Responses to each question can be characterized along a scale which depicts the variation in the degree to which teachers — who are to benefit from the in-service program — are central to the planning of that program. Taken together, these four scales provide a profile of the proposed program. The more that teachers are involved in planning (responses tend to cluster at the bottom end of each scale), the more "bottom-up" the profile is said to be. The more that others, external to the program, are involved in the planning (responses tend to cluster at the top end of each scale), the more "top down" the profile is said to be. Consistent with our assumption about self-direction and autonomy, "the more 'bottom-up' a profile, the easier it is, in general, to meet the conditions for valued staff development programs; the more 'top-down' a profile, the harder it is, in general, to meet the conditions for valued staff development programs. The stress placed on the expression 'in general' is critical. There are many exceptions to this generalization" (Fenstermacher & Berliner, 1983, pp. 7-8).

Planning a teacher enhancement program should be guided by a consideration of four important features of the proposed program's organizational setting. First, "How was the in-service program initiated?" Programs can be proposed internally or externally, bottom-up or top-down, selected or imposed. At one end of this scale would be an example of the individually guided approach in which teachers, working independently or in small groups, take complete responsibility for proposing and planning a set of activities intended to familiarize themselves with a new science curriculum package. At the other end might be the training approach — a Saturday workshop for example, planned by the district administration and sanctioned by the school board, which is intended to increase teachers' awareness of gender stereotyping in science and mathematics classes.

Second, "What is the purpose of the in-service program?" A teacher enhancement program can be understood in terms of its organizational purpose: compliance with requirements imposed by outside agents; remediation of knowledge, skills, and attitudes; or enrichment or extension of teachers' knowledge, skills, and attitudes beyond present levels. Thus, this scale is anchored by reference to three points: compliance at one end, remediation in the middle, and enrichment at the other end.

Third, "Which and how many educators will participate?" Is the activity intended for an individual teacher, a group of teachers, an entire school staff, teachers districtwide by grade level, or the entire district? To the degree that the intended audience of any teacher enhancement program grows, the likelihood that the activity will have a "top-down" quality increases. Issues of economy may argue for larger enhancement programs which are able, for instance, to make more efficient use of funds to employ high quality experts or to access equipment or facilities that are out of the reach of smaller programs. Nevertheless, such potential advantages of size must be weighed against the tendency of larger programs to take on a "top-down" quality, to become more remote from the particular needs and interests of the participants, and to reduce the degree to which participating teachers can exercise control over their own learning.

In addition to the number of those participating, the professional roles of the participants is important. Many projects recommend the participation of teams of teachers or teachers and administrators whenever possible. This encourages and supports accomplishment of the enhancement activity's goals. If they cannot involve administrators directly in the program's activities, many programs offer abbreviated sessions to orient the administrators to the content, processes, and materials the teachers will receive (Ellis, 1990).

Fourth, "Why did the participants become involved?" Participation can range from one extreme, in which it is completely mandated by an external authority, to the other, in which it is entirely voluntary. For example, teachers may attend to meet credential requirements or site or district administration directives, or they may attend because they perceive that the activity will meet some personally recognized professional need. It is assumed that "top-down," mandated participation is perceived, on the whole, as having less potential for being valuable and contributing to change than is "bottom-up," voluntary participation. This is not to say that teachers cannot gain as much from a mandated experience as they can from a voluntary one. Rather, the potential for gain is, in most cases, higher under conditions which respect the teachers' self-direction and autonomy.

Examination of the Science and Technology course offered at East Tennessee State University (Rhoton & Pafford, 1990) illustrates how an in-service program can be described in terms of the top-down/bottom-up profiles presented by these four scales. First, initiation of the planning process would be located between the "external" and "internal" extremes illustrated on the first scale in Figure 5-1. That is, although the in-service program was initiated externally with an offer from the University faculty to assist local science teachers, the process actually began two years prior to the actual course initiation with discussion and correspondence with elementary and secondary school teachers in the university's area to identify basic needs in their science programs. These initial conversations were augmented by the administration of a questionnaire that was completed by over 300 teachers. The results, which helped to answer the second question on Figure 5-1 ("For what purpose?"), clearly identified "enrichment" needs of teachers rather than "compliance" or even "remediation" needs. Using these data, faculty from the university met with a committee consisting of teachers, representatives of the university's administration, and local business and industry representatives to plan the course content and delivery system. Although a large number of teachers participated in the program — ("Who participates?" on Figure 5-1), participation was strictly voluntary. The directors of this program attribute much of their success to teacher planning and participation — features that, when applied to the schematic presented in Figure 5-1, result in a predominantly bottom-up planning profile.

An interesting case of a change in a program's top-down/bottom-up planning profile is presented by the University of Houston-Clear Lake's program, described above. This program, which focused on cooperative groups in science teaching, was initiated by faculty at the university in response to a need they perceived to improve science teaching. The content of the program was developed by the faculty from their extensive examination and synthesis of the literature on cooperative learning. But teachers had numerous and significant reservations about the appropriateness of some of the content. On the basis of this feedback, the program was changed to an inquiry approach, with teachers collaborating with content and pedagogy specialists from the university. The teachers defined their own inquiry problems and developed and tested their own hypotheses. Working in small groups, the teachers eagerly undertook a substantial number of different investigations. In effect, this change altered the planning process from top-down to bottom-up.

The bottom-up approach is consistent with our assumption of teacher autonomy. The Physical Science Workshop sponsored by the University of Wisconsin-River Falls (Sukow, 1990) provides a concrete example of a planning process that provided considerable latitude for teacher autonomy. In this program, which used the development and improvement approach, participants prepared teaching materials that used exhibits at a local science museum. The exhibits were patterned on those offered by the San Francisco Exploratorium, which involves users in hands-on manipulation of variables. Topics covered include mechanics, fluids, waves, acoustics, electromagnetism, light, color, geometrical optics, physical optics, and modern physics. Teachers were offered a large number of interactive exhibits from which to select, and thus could "learn about inquiry with exhibits of their choice; exhibits they find interesting, exhibits they are comfortable with, and exhibits which will be helpful in teaching their science curriculum" (Sukow, 1990, p. 43).

5.2 Forward-Looking Evaluation

During the preparation stage of any in-service program, planners and school district decision makers should evaluate the program under development. When engaging in such "forward-looking" evaluation, Fenstermacher and Berliner (1983) suggest that three fundamental questions should be asked:

> "Is it worth doing?" Is there evidence that the program is worthwhile, that it has a conceptual basis, that it is fair and is not harmful to participants, and that it can be supported by research, evaluation, or critical experience?
>
> "Will it be successful?" Evidence of potential success includes (a) clearly stated program goals that are closely related to teachers' work; (b) program staff who are competent in teaching adults and in modeling the skills or techniques underlying the in-service program; (c) program content that meets the needs, interests, and abilities of teachers; (d) program content that is sufficiently concrete to make its applications in the classroom clear; and (e) provision of sufficient time for recipients to learn, practice, master, and apply the content of the training.
>
> "Will the in-service program be meritorious?" Evidence of potential merit includes a program that (a) is timely and consistent with plans teachers have for their work; (b) provides a range of activities that permit variation in the ways recipients participate in the program and use what they learn; (c) provides positive incentives to recipients for their participation, both during the program and during its classroom implementation; and (d) provides funds, facilities, incentives, time, and personal assistance and encouragement during classroom implementation.

Unfortunately our review of in-service education programs did not turn up an example of forward-looking evaluation. Fenstermacher and Berliner do provide a concrete example, although not related to science:

> A superintendent wants everyone in his district to learn the record-keeping techniques necessary to comply with Public Law PL 94-142, the law Congress passed regarding the treatment of the handicapped in the schools. She recommends workshops for all her faculty in order to learn how to build Individualized Educational Plans (IEPs); how to document their teaching; how to document the learning of special students; and how to keep records of the meetings with the school psychologist and the parents of special students. She asks her supervisory personnel in the district to learn the law, talk with community leaders, teacher's associations, and others, and then provide a curriculum for the teaching staff of the district (1983, p. 50.)

This evaluation focused on the same three general evaluation questions discussed above: (1) Is the proposal worthwhile? Although the program may be tied to individualized instruction, the program's activities are not easily justified on the basis of the underlying instructional theory. The program can be justified by teachers as a good thing to do to comply with Public Law PL-94-142, and since it does not pose harm for them, the program can be considered morally appropriate. There is, however, no indication that the superintendent examined the effects of similar programs, so evidence from the research or evaluation knowledge base is lacking. (2) Might the proposed in-service program be successful? Fenstermacher and Berliner concluded that the proposal met the conditions of success. (3) Is the proposal meritorious? In a word, no. Teachers were not involved in planning and determining the content. Identical procedures had to be followed in every classroom. Neither incentives nor follow-up were provided.

5.2.1 Program Implementation

In implementing an in-service program, three issues deserve special attention: the source of the content that is introduced by the enhancement program, actual delivery of that content, and formative evaluation efforts intended to provide information useful in adjusting and improving the in-service program as it proceeds.

5.2.2 Source of Content

We are often tempted to think of the source of the content in a teacher enhancement program as an expert authority (e.g., a prestigious researcher or a practitioner with highly developed skills). This expert may know a particular set of scientific concepts or processes or may be an authority on a particular teaching approach. The expert's task is to "present" to the participating teachers the content to be learned. Such a view of the source of content is consistent with the training approach described above.

A typical example of an enhancement program which depends on experts is the EQUALS in Computer Technology Project of Lawrence Hall of Science (Gilliland, 1984). This program, which seeks to attract and retain women and minority students, provides five-day workshops on topics such as computer operation, thinking skills, problem solving, software review and evaluation, Logo programming, classroom management, and career education. The workshop presenters (i.e., the sources of the content), are experts from Lawrence Hall of Science.

The Mountain View Teacher Center (Apelman, 1979) also used experts as a primary source of content, but in a much different way. The Center employed subject-matter experts as advisors to individual teachers. Consistent with the Center's "individually guided" approach, contact between teacher and content expert was initiated by the teacher as he or she defined a particular curriculum or subject-matter need. The advisor met with teachers individually or, when teachers shared common needs, as a group. The meetings were often conducted at the teacher's school and may have included opportunities for the expert to visit and observe the classroom.

However common it is, the view of the expert as the source of content is quite limiting and by no means exhausts the range of sources which may be tapped by the other four approaches. For example, if the inquiry approach predominates in an enhancement program (i.e., if a team of teachers and researchers are engaged in a process of seeking answers to questions of educational practice), a researcher who presents details of a data collection technique would be regarded as a source of content. Likewise, the teacher who offers information to the research team regarding school regulations, patterns of pupil play, or a history of interactions with parents is another source. Indeed, the team members, recognizing an emerging need, may decide to search for a new content source for information on a particular scientific phenomenon that will be taught in the teachers' classes. Similarly, other approaches may tap different sources of content. For example, teachers participating as a team in a development or improvement-based program, may treat each other as sources of content, and the source of content in the observation/assessment approach may be the teachers' and students' behavior, as interpreted by a trained observer.

The University of Houston-Clear Lake program, in which a training approach was transformed into an inquiry approach, changed its source of content. Teachers were cast in the role of teacher-researchers and became a significant source of content based on their own classroom experiences. The formal content they learned from university faculty in their first year was augmented and modified by their own contributions.

5.2.3 Content Delivery

Content may be delivered by any of a variety of methods, including large-group lecture, small-group discussions, individual work, teleconferences, instructional television, and printed materials. The New Mexico Department of Education (Rowland & Stuessy, 1990), for example, sought to improve elementary school teachers' basic science process skills, including observation, communication, classification, prediction, inference, and measurement. Using a variation of the training approach, this program developed a set of "kits" that captured the expertise of university science educators on videotape and printed materials. The university educators used the kits to train a set of selected elementary school "mentor teachers," teachers who in turn used the kits to train still other teachers.

Whatever the method of content delivery, the knowledge and skills that teachers are expected to construct should be illustrated or modeled through a demonstration of their use in classroom settings, and they should be practiced. Modeling may be provided "live," using pupils, teachers, and situations. Alternatively, audiovisual media, such as videotape or film, may be used to model the expected behavior.

Live demonstrations were a major component of the Teachers in Physical Science Workshops sponsored by the University of Wisconsin-River Falls:

> To encourage sharing between teachers and their colleagues and to introduce a multiplier effect, each workshop teacher was required to give one or more demonstrations of his/her favorite science lesson (. . . .) These presentations have stimulated many questions, encouraged reference back to original exhibits, and increased the self-esteem of teachers. In several instances, demonstrations given early by elementary teachers, somewhat apologetically, have been taken with enthusiasm by middle school teachers, embellished, and integrated into their teaching (Sukow, 1990, p. 45).

Practice may be the most important and, at the same time, the least used technique in teacher enhancement programs:

> In the same way that we would not expect an experienced surgeon to utilize a new procedure without "hands-on" clinical experience, we should not expect a teacher to do the same thing either. Typically, inservice education has consisted, at its best, of the introduction of classroom skills, usually on a college campus or in a school building when there are no children present. Rarely, if ever, does one find a situation where teachers are given the opportunity to practice the new skill under the supervision of an expert (Yarger, 1982, p. 37-38).

There are some rules of thumb for incorporating practice into teacher enhancement programs:

Timing

- Provide adequate time for practice so that participants can try out their newly acquired learning under the direction and guidance of the enhancement provider.

- Put practice close to initial learning to increase the likelihood that learning will be retained and transferred (Parry, 1990).

- Distribute practice over several short sessions to produce results that are superior to practice which is concentrated in one or a few longer sessions.

Feedback

- Provide immediate feedback to practice that is focused on specifics of that performance.
- Use participants as sources of feedback for one another (the observation and assessment approach is built primarily on the provision of feedback to teachers).

Settings

- Carefully manipulate the settings in which practice occurs, initially under simulated conditions using peers who assume the roles of pupils.[4]
- Vary the practice setting, moving from comfortable and controllable but artificial settings toward more realistic settings which mimic actual classrooms.
- Provide practice with feedback in teachers' own classrooms.

5.2.4 Formative Evaluation

This type of evaluation, the purpose of which is to guide program improvement, provides detailed information about "what works" and "what doesn't work" during the development and implementation of an in-service program. Such information is used to modify program components, add new ones where client need is clearly indicated, and delete others that are not working or are not needed.

The range of evaluation methods is quite wide, depending on the nature and importance of the information needed to develop programs and make improvements. Typically, observation by staff members participating in a program try-out, interviews with participants, review of documents (e.g., program proposal), and questionnaires are used. (Indeed, the issues of worth, success, and merit described under an evaluation for program selection might very well form the basis of a formative evaluation for inquiry into what works.) In some cases, however, an important decision about, for example, whether or not to incorporate a module, or to use one instructional strategy (e.g., "hands-on") or another (e.g., video) might warrant a small randomized experiment or quasi-experiment in order to decide.

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[4] *Such simulations have several advantages. Recognizing the importance of fostering appropriate attitudes, Fraser-Abder (1989) emphasizes the need for teachers to develop a high level of comfort with new techniques for teaching science and even with using science equipment and specimens in the classroom. Simulated settings offer a relatively low-risk opportunity for initial practice without fear of adversely affecting real learners. Simulated settings for practice also offer the advantage of increasing the control that the trainer has over the practice setting. Without having to deal with the often unpredictable exigencies of real classrooms, practice in simulated settings can proceed in a rather deliberate and purposeful manner which focuses directly on the knowledge and skills which are the targets of the training. Simulated settings do have their drawbacks: Generally speaking, as they decrease in verisimilitude compared with the actual classroom settings in which teachers will eventually work, they reduce the potential for adequate transfer to those classrooms.*

Ellis and Kuerbis (1991) conducted an exemplary formative evaluation of an enhancement program (ENLIST Micros) for improving teachers' knowledge of, skills in, and attitudes about educational computing in science education. The evaluation was linked closely with program development so that the first major task of the evaluation was to help developers determine the most important goals for the program. To this end the evaluation started with a review of an initial set of objectives by science and computer educators. Next, teachers, administrators, and professors rated the objectives according to their importance. Only those objectives that were considered "important" by at least 75 percent of the reviewers were incorporated into the enhancement program. To organize the objectives for training development, the ratings were factor analyzed, yielding six major constructs underlying computer literacy for science teachers.

In a second stage, pilot materials were developed to meet the objectives and an advisory committee reviewed and evaluated the instructional material. From their comments and suggestions, "experimental material" was developed. This material consisted of a text and an annotated guide for workshop leaders, videotapes of interviews with teachers, and scenes depicting students using computers in science classrooms. In a third stage of evaluation, the experimental material was field tested with 18 groups of pre-service and in-service teachers across the country.

Data from questionnaires and interviews with instructors, expert observation during the workshops, and questionnaires and outcome measures for participants were collected. From the questionnaires, both instructors and participants gave the materials and the program a high rating. The outcome measures assessed knowledge of, skills in, and attitudes about educational computing within a pretest-posttest design. Significant differences between the pretest and the posttest means were found. From this evaluation, it was concluded that the materials were effective in improving the participants' knowledge and attitudes about educational computing.

In a fourth stage of the evaluation, a follow-up survey measured the degree to which participating teachers implemented computers in their classrooms. Results showed that 67 percent of the participants were not using computers one year after the workshop. Participants revealed that they needed both follow-up support from experts and local financial support for software and hardware in order to use computers in class. After two years of field testing and implementation studies, a new revision of the enhancement program, ENLIST Micros 2, was developed on the basis of these findings and fielded.

In another example of an evaluation in which program revision played a large part, Gayford (1987) produced a series of eight workshop modules, each three hours in duration, on teaching biotechnology subjects (e.g., genetic manipulation, enzymology) in elementary school. Within each module a number of activities were provided; and each module could be adapted to local needs by combining various parts of the modules rather than following them through from beginning to end. The materials and activities for each module were extensively and repeatedly tried out with over 200 teachers in six different districts. Following each trial participants and, where appropriate, "tutors" completed evaluation forms inquiring about the extent to which each module's goals had been met in terms of issues addressed, information and "how-to" skills provided, and relevance to classroom life. Of particular concern was the ability of the program to meet needs of a varied teacher audience. During the evaluation it became apparent that most teachers needed experience in basic microbiological techniques including preparation, safety and handling of materials, and maintenance of cultures. The knowledge and skills required to use these techniques were subsequently incorporated into the in-service program, and another series of tryouts were conducted. Unfortunately, this type of "formative" evaluation is noticeably absent in most in-service science education programs (Knapp, Shields, St. John, Zucker, & Stearns, 1988; Fitzsimmons, Carlson, Burnham, Heinig, & Stoner, 1991).

Hall and Loucks' (1978) Concern-Based Adoption Model (CBAM) is popular for formative evaluation with NSF projects but it is misused. The information provided by CBAM does not meet the program development and improvement needs of the in-service program itself (Hord, Rutherford, Huling-Austin, & Hall, 1987). Rather, CBAM focuses on the *adoption* of innovative in-service programs. Consequently, we discuss the CBAM model under Summative Evaluation (see section 5.2.8).

5.2.5 Follow-up

The third set of design components of teacher enhancement programs are of concern when the teacher is back in the classroom, ready to implement the newly acquired skills or knowledge. Will the teacher succeed in improving teaching and learning in the classroom as a result of the enhancement program? Three components of an in-service program can play important roles: coaching, support, and summative evaluation.

5.2.6 Coaching

The potential for teachers to adopt practices that lead to improvement in teaching and learning in the classroom may be increased by providing additional practice accompanied by feedback in the teacher's classroom. This tack is termed "coaching" (Costa & Garmston, 1987; Joyce and Showers, 1988). Consistent with our assumption of the importance of teacher thinking, Costa and Garmston emphasize the "cognitive coach's" use of questioning strategies that reveal the teacher's persistent perceptions of teaching and learning actions in his or her classroom, as well as the mental maps used by the teacher to give meaning to those perceptions. The coach uses observation techniques to describe classroom behaviors and encourages teachers to compare such descriptions to their own perceptions and understandings.

Coaching is a basic component found in the observation/assessment approach to teacher enhancement, where the teacher identifies an area of concern (e.g., cooperative groups, classroom management) and agrees with the observer on particular teaching and learning actions related to this concern. The coach observes the teacher and students in the learning setting and then provides feedback intended to assist the teacher in reexamining both his or her own actions and the assumptions on which they are based.

Other approaches may also incorporate coaching. For example, resource teachers are an integral component of Project SEED's training approach. These coaches visit classrooms on a weekly basis, modeling hands-on science teaching and coaching teachers as they apply what they have learned in workshops. Indeed, teachers using the individually guided, inquiry, and development and improvement approaches may also request coaching and feedback. For these teachers, coaching may involve the examination and critique of a document, such as a science curriculum guide or course outline, with feedback provided in written form.

At the Mountain View Center (Apelman, 1979), which was based on the individually guided approach, various types of advisors, including specialists in subject matter and experts in classroom pedagogical approaches, were employed to provide assistance to teachers. On request, they gave help in curriculum development and implementation, classroom organization, acquisition of materials, child development questions, and relationships with administrators, parents, and paraprofessionals. These advisors had no evaluative or supervisory functions. They were present at the invitation of the teachers, and their success depended on a relationship of mutual respect and trust.

5.2.7 Support

Developers of teacher enhancement programs have increasingly come to recognize the utility of providing substantial support to teachers attempting to implement in their classrooms the knowledge and skills learned in the program. One-shot workshops with no follow-up support have proven ineffective for changing teacher behavior or increasing student learning. Indeed, NSF guidelines state that teacher enhancement projects should include follow-up activities that help teachers implement both content and teaching strategies in the classroom.

Follow-up activities may take several forms, including formal seminars in which participants have the opportunity to build on new knowledge and skills, informal gatherings in which participants share their experiences implementing the targets of training, and newsletters. Some science enhancement programs provide teachers an opportunity to visit other classrooms to observe and coach one another (Ross, 1990). Some build support by using teacher teams consisting of teachers from the same school, teachers of the same subject area, or teachers and an administrator from the same school site (Ellis, 1990).

The ENLIST Micros Project provides support in the form of 61 previously trained teachers and administrators, each of whom works with 3 to 5 teachers new to the project. Participants attend seminars during the year to refine their skills, share experiences, and collaborate on solving problems that have arisen during program implementation. They are also introduced to appropriate software and techniques for integrating the computer into their science curriculum (Ellis & Kuerbis, 1988). Finally, teachers are provided an opportunity to pursue additional study with those expressing similar interests.

Other programs offer a combination of support services. For example, the Cycle 22 Project (Rhodes, 1988) offers several support services to teachers in the year following their initial three week study of solar activity at the Roberson-Kopernik Observatory. These services include three additional seminars, four sharing sessions, a bimonthly newsletter, and use of a hot line and a computer bulletin board to resolve problems and share information.

In addition to support provided by the teacher enhancement program providers, support from the teacher's school and district is also important. The role of the site administrator requires "commitment, attention to detail, and sufficient time," in order to negotiate for optimal teacher enhancement activities (Bowyer, Ponzio, & Lundholm, 1987, p. 817). The site administrator can ensure that materials necessary to new teaching approaches are provided and that teacher schedules are adjusted where necessary to accommodate peer observations and coaching.

Project Catalyst (Carlson, 1990) asserts that the extensive support offered to their participating teachers is most effective when it is provided by the teachers' own school districts. Indeed, district administration commitment to the teachers' involvement in the project is required in the form of written and financial support. Districts pay for all of the full-day released time required for teachers who participate in the program. To promote involvement and communication among participants, this program publishes a newsletter, provides a teacher-created curriculum and resource library of new earth science teaching materials, and organizes field trips and conferences.

5.2.8 Summative Evaluation

After the in-service program has been implemented and institutionalized, it is appropriate to address the "bottom line," or the effectiveness of the program. Information about program effectiveness focuses not "simply [on] whether participants enjoyed particular activities, but what difference these activities made in their classrooms" (Jones & Lowe, 1990). Summative evaluation methods are diverse (quantitative and qualitative) and sophisticated because both causal inferences and cost data may be sought. In some cases alternative programs are compared as to their effects and costs. Such information is often used by funding agencies to decide whether to continue support for projects or to convince Congress of the value of what the agency is doing. School decision makers use the information in selecting in-service programs.

Again it is difficult to find examples of "summative" evaluations of in-service education programs. Harvard's Project Physics is a unique example of summative science curriculum evaluation that employed a randomized experimental design to assess its effects. Welch and Walberg (1972) conducted a study in which 72 teachers were randomly assigned to an experimental ($n=46$) or control ($n=26$) condition. Teachers in the experimental group studied physics over six weeks and took a series of tests that would be given to their students in the new curriculum. These teachers then taught the course according to Project Physics, and administered pre-, mid-, and post-tests to their students. Teachers in the control group attended two-day sessions where they took the same tests, but they taught their regular physics course.

Eleven different instruments (e.g., test of understanding science, physical science interest measure, learning environment inventory) were used to evaluate six different goals of the project (cognitive, interest, learning environment, course reaction, attitude, and physics perception). Significant differences between experimental and control groups were found in the attitude, course reaction, and physics perception areas. This study did not include the cost of implementing this curriculum, but it did include the costs of the national evaluation as part of the report.

Major summative evaluations of in-service programs using experimental designs where teachers are randomly assigned to in-service programs are seldom used because of the cost and sophistication of the evaluation methods needed. The next best alternative to the randomized experiment is the quasi-experiment. Such experiments provide control conditions, comparison groups, or replication, but randomization of the units of analysis is not present. More typically, however, in-service education is evaluated by a "one-shot" pretest-posttest design. Unfortunately, this approach suffers from a major weakness. Absence of a control or comparison group, that did not experience the in-service program leaves room for competing explanations or counter-interpretations of the results. In other words, without a control or comparison group, one cannot be sure that the in-service program alone accounted for the pre and post-program differences. In the end, for a select number of major in-service science education programs — ones that work with teachers in the use of hands-on science curricula and are intended to be "exportable" to other sites — evaluations for program effectiveness might best undertake randomized experiments. For most programs, however, such an investment is not warranted. Rather, collecting data on telling questions about the program provides important insights into the program's effects.

A one-day biotechnology course with eight in-service teachers (Lock & Dunkerton, 1989), dealt with the limitations of a pretest-posttest design by replicating the design six times. The course was offered six times to eight in-service teachers on each occasion. The goals of the one-day course were to (1) enhance teacher knowledge and use of practical work in biotechnology; (2) develop teacher knowledge and use of problem-solving investigations in a biotechnological context; (3) extend teacher knowledge and use of theoretical aspects of biotechnology; and (4) explore possible ways in which teachers of science can work cooperatively in the area of biotechnology. The course was highly practical, with hands-on experience with experimental work that could be done by students in secondary schools. The activities were structured in such a way that the relationship between science and technology was evident.

According to the authors, the central issue in evaluating the course was to determine the extent to which it influenced both teacher practice in the classroom and the work offered to pupils in the classroom. The evaluation of the course was carried out by using six replications of pre- and post-course questionnaires, including sections on (1) teacher background (gender, subjects taught, years of teaching experience), (2) knowledge and use of biotechnology in school contexts, (3) attitudes to the introduction of biotechnology into school courses, and (4) level and extent of cooperative work between the science and other departments. For the post-course questionnaire, a fifth section was added about the utility of the course and whether it could influence the nature and extent of cooperation between departments. Results showed that the aims related to teacher knowledge and use of practical work, problem-solving investigations, and theoretical work on biotechnology were partially achieved. The major success was in relation to practical work, whereas the least success was evident in relation to theoretical work, a topic that was not a major focus of the course. It is quite unlikely that across six occasions some extraneous cause consistently affected pretest-posttest changes.

An alternative to randomized experiments and quasi-experiments for summative evaluation is one that provides in-service education developers, funding agencies, and potential program users detailed descriptions of in-service programs that go beyond sterile research site descriptions and statistical summaries. Rather this alternative seeks to place varied audiences inside the program to "see" how it works. This is a highly personalized evaluation (cf. Lorenz, 1982), one which draws heavily on qualitative methods such as interviews, participant observations, and examination of documentary evidence. The intent is for each audience to make its own judgment of the program's relevance, value, and usefulness. More specifically, this type of evaluation provides an "insider" (e.g., teacher, trainer, administrator) perspective, conveying an image or multiple images of the program (cf. Stake, 1991). Such perspectives foster understanding of activities and how they are valued by participants in a given setting.

Evaluation of in-service education programs using these qualitative techniques is rare. The work of Stake and Easley (1978) provides an example of this approach, although not within the context of in-service education. A collection of field observations of science teaching and learning in American public schools was used to describe the status of K-12 science education in the United States in the 1976-77 school year. Eleven high schools were selected that varied as to urbanicity, geographical location, racial diversity, socioeconomic status, and curricular innovativeness. Seeing, rather than measuring, was the goal of the project. The evaluators relied on field observations and interviews as a means of recording different images and meanings about issues such as conceptualizations of science, the place of science in the curriculum, and science instruction. The project helped to identify and understand these major issues as they were perceived in the field by teachers, administrators, students, parents, and curriculum supervisors.

Field work was carried out in three overlapping phases: (1) case studies (e.g., site selection and description of the population characteristics, funding sources, and descriptive socioeconomic statistics), (2) site visits (i.e., field observations), and (3) a national survey that asked for demographic, biographic, scenario, and science education information. In an oversimplification of the results, it was found at that time (probably not very different from the current situation) that science education emphasized basic skills such as reading and computation and only occasionally made efforts to do more than "read about" science. Science was seldom taught as scientific inquiry. Rather, teachers worked hard to prepare the students for paper-and-pencil achievement tests. Nevertheless, the picture of each site varied in important ways. Each was uniquely influenced by its particular administrators, parents, students, and technical, professional, economic, and social characteristics — the "insider's" perspective.

Qualitative designs for summative purposes may go no further than description. Some evaluators do not presume to be in a position to judge the merit or success of a program. For them, providing a richly detailed description of a program which may be used by others for making judgments is enough. Others, however, believe that the evaluator's informed judgment as to merit and success are warranted. Indeed, it is argued that the evaluator's detached, full perspective on the in-service program makes his or her informed judgment not only valuable but imperative. Our goal here is simply to point out but not resolve this controversy.

Evaluation of a hands-on, in-service program in the Instructional Technology Project conducted at the University of California — Santa Barbara (Copeland & de la Cruz, 1990) provides an example of a combined quantitative-qualitative analysis to address program effectiveness. The program was designed to enable secondary school social-science teachers to adopt innovations in electronic technologies (e.g., computers, videotape, laser disc players) in their own teaching and to advocate such adoption beyond their classrooms to other teachers with whom they worked. Evaluators used a variety of data gathering techniques. Questionnaires were used to collect demographic information, prior technology experience information, and leadership experience information about the teachers before, and at the end of, the summer component of the program and again at the end of the year-long implementation component. Individual and group interviews were used to collect information on teachers' classroom use and advocacy of technology. Open-ended written responses were employed to capture teachers' perceptions of the program's effects on their professional behavior. When this detailed data-set was examined, it provided a mixed view of the program's "success." It was found that only about two-thirds of the teachers reported changing their classroom practices with technology during the year the project lasted, and less than half advocated innovation to their peers.

The extensiveness and rich detail of the collected data permitted the evaluators to go beyond simply describing the limited success of the project. They were able to examine why the program was less successful than desired. The data were brought to bear on a set of possible explanations, such as whether the initial institute training was inadequate (rejected in light of pre-post delayed questionnaire responses and interview data), whether the schools in which the participants taught constrained technology use and advocacy (a localized but not decisive factor), whether lack of personal, collegial support limited use (not a factor in teams attending the institute that had a prior history of working together, but a problem with ad hoc teams), and the like. In the end, the evaluators were able not only to describe the success of this Technology Institute, but also to present a set of recommendations for consideration when planning the next Institute.

Hall and Loucks's CBAM technique is another descriptive type of evaluation frequently used to evaluate the degree to which an innovation has been adopted. This model reflects program adoption along three dimensions: *Innovation Configurations (IC)* focuses on identifying and describing the various forms that an innovation can take when teachers are adopting it to their particular conditions. *Stages of Concerns Questionnaire (SoCQ)* focuses on the concerns that teachers experience during the change. According to the model, in changing their behavior teachers move through seven stages of concerns: (0) awareness (little concern about the innovation), (1) informational (interest shifts from self to understanding the innovation), (2) personal (individuals are uncertain about the demands of the innovation), (4) management (processes and tasks of using the innovation), (4) consequence (impact of the innovation on students), (5) collaboration (coordination with others), and (6) refocusing (benefits from the innovation). *Levels of Use* portrays the way teachers and others work with innovations (i.e., teachers who are actually employing the new practices efficiently, those who are still experimenting with them, and those who have not yet started). Taken together, these three dimensions provide a picture of the degree to which the program has been adopted by a given agency.

Our discussion to this point has centered on describing teacher enhancement programs and their evaluation during program planning, implementation, and follow-up. Two concluding issues need to be addressed. The first concerns the magnitude of impact of a given program on numbers of teachers and students. We provide one commonly used strategy to achieve a large-scale impact with a teacher enhancement program. The second concerns the issue of evaluation. We provide some guiding questions for teacher enhancement programs to raise in crafting an evaluation.

5.2.9 Strategy for Large-Scale Impact of Staff Development

In-service education programs intend to assist participating teachers in improving the teaching and learning that occurs in their own classrooms. Many in-service programs go one step further, however, by asking participating teachers to share what they have learned with their colleagues who did not attend the program. The assumption is that teachers can be cast as "change agents" in their local schools. That is, teachers will serve as "evangelists," bringing new insights, information, and teaching approaches to the schools and districts from which they were recruited.

This is not a new approach; it was, for example, a basic strategy of the Office of Education's "Experienced Teacher Fellowship Programs" in the late 1960s. Program directors continue to assume that casting teachers as evangelists offers a way to increase the influence that funding agencies and the programs they support have on the schools of the nation. Ross (1990) investigated the effects of training "key teachers," representing each school connected to the Ontario Dissemination Efforts Supporting School Improvement (DESSI) Project, to "pass the message on to others" at their respective sites after training. The colleagues with whom these "key teachers" worked showed no less facility for improving 4th grade students' problem-solving skills than did teachers who participated directly in the staff-conducted in-service program, which was much more expensive to conduct.

Experience over the years from this and a number of other projects suggests that, while success is not automatic, it can be encouraged by attention to both purposeful preparation and specific support of the teachers in the program. Teachers require specific instruction to prepare them to assume responsibilities for training colleagues (i.e., for training outside their own classrooms). Typically, however, teachers have not had the opportunity in their professional preparation to consider the very personal nature of change when individuals are confronted with the possibility of adopting any new innovation. In their work on the adoption of innovations by teachers, Hall and Loucks (1978) focus on the varying levels of concern that individual teachers may have when faced with using an innovation (e.g., a new teaching approach), in their classrooms. Hall and Loucks maintain that in-service programs cannot assume that all participants are operating at any one level of concern with relation to the target innovation and that success is best achieved when each teacher's concerns are directly met. Familiarity with the CBAM model may be of assistance to participant teachers as they look forward to working with colleagues who might harbor quite different concerns about the innovations being shared with them.

In preparing teachers to share the products of their own in-service training with colleagues, many programs familiarize participants with issues of adult learning and in-service program design and with specific skills, such as those necessary for successful peer coaching. Furthermore, teachers are provided time to design and prepare workshops that they will use when they return to their schools. They may be allowed to work in teams and to practice their own presentations on one another as "dry runs" before actually facing their colleagues back home. The Basic Science Process Skills Inservice Workshop, conducted by the New Mexico Department of Education (Rowland & Stuessy, 1990), offers such specialized training to "mentor teachers" so that they can "replace" university professors in training. Once prepared, these mentors then work with their peers across the state in the use of specially prepared science teaching kits.

In addition to preparation, participating teachers require support. As described above, both material and psychological support is crucial to helping teachers carry innovations home and use them in their own classrooms. Such support is equally valuable to teachers who undertake to share what they have learned with their colleagues. It is crucial that the physical support necessary for such evangelism be provided. Directors of in-service programs may be unaware of the conditions under which many of their participating teachers work. For example, school district administrators have been known to ask program participants to design and give an "in-service day" to their colleagues, without offering sufficient support in terms of time and resources. Moreover, the administration may assume that giving the participant the opportunity to "tell" what they learned is sufficient. Thus they may not schedule adequate time for the colleague teachers to involve themselves in hands-on learning or for the presenting teachers to visit classrooms and model for or coach their colleagues. Furthermore, the administration may not make available to the attendees the necessary materials (e.g., computer hardware and software, hands-on manipulatives) for them to try what they have learned in their own classrooms.

Under such unsupportive conditions, the presenting teacher is faced with predictable failure when colleagues are unable to experiment with what is being taught. To overcome these difficulties, in-service program directors have been known to require that commitments of time and materials, written by district administrations and even endorsed by school boards, be supplied as part of each teacher's application package.

Psychological support is equally important to success in evangelism. After sending teachers home, programs may schedule follow-up meetings in which participants share their successes and failures and help one another to plan and implement local training experiences. The sense that "I am not alone" appears to be helpful in enabling teachers to venture out of their own classrooms to offer something of what they know to their colleagues.

A very powerful psychological support mechanism is the teacher team. The University of California-Santa Barbara Instructional Technology Project required applications from teams of three or four teachers from the same school or district as opposed to the more typical individual application. The evaluators found the most powerful predictor of success to be membership in a functioning team. The emphasis here is on "functioning." The interviews conducted as part of the evaluation revealed that, although all participants ostensibly came as members of teams, in fact many of the teams were artificial, having been formed in their school districts only for the purpose of applying to the project. The members of these "teams" had not worked together before beginning the in-service program and did not work together after its termination. These teachers demonstrated little tendency to share what they had learned with their other school colleagues. In sharp contrast, those participants who constituted real teams (i.e., who had a history of collaborating and intended to continue such collaboration), demonstrated consistent and effective efforts to mount evangelistic projects upon their return home. They were the success stories of the project.

5.3 Crafting Evaluation

Evaluation is an integral component of in-service education programs. Indeed, we could not describe in-service programs without describing appropriate evaluations as well. Widespread agreement, if not consensus, holds, then, that in-service education programs should be evaluated. Because of the centrality of the evaluation issue to the success of in-service science education, five additional questions focused on crafting a program evaluation are considered here.

5.3.1 What Aspects Of the Program Should Be Evaluated?

In-service education programs are complex, having numerous components and potential outcomes. Should the components be evaluated individually or in combination? On what outcomes? Some recommend a systemic evaluation, one that provides information about different aspects of the program and their interrelationships. This kind of evaluation includes *background* information on participants and the program context, such as local education context, that would foster or impede program success; *goals* of the program, such as participants' understanding of the rationale and philosophy and the specific teaching activities to be changed; *classroom consequences*, such as allocated time for activities specifically included in in-service education, documentation of engaged time, and observation of interactions with students; and *outcomes* on students using program-specific and standardized indicators (Romberg & Price, 1983; National In-service Network, 1980).

Romberg and Price (1983) reported a systemic evaluation of staff development for curriculum reform in all subject areas in the Berea (Ohio) City School District. The evaluation sought to answer four questions: (1) What is the background of students, staff, and community?

To respond, staff in each school described, in writing, the school's students, staff, and social environment. Based on these descriptions, they then decided on school goals and the means to reach them. (2) What new curricular programs are being used? School administrators were particularly concerned about implementation of curriculum reform because they viewed it as prerequisite to student achievement. Of particular interest were teachers' short- and long-run lesson plans, their daily collaborations with one another, and their classroom interactions with students in a manner consistent with reform. (3) What data describe the student learning process? Data were collected on how much time teachers allocated for teaching new curricula; how much time students were actually engaged in a particular skill, concept, or content area; and which activities worked and which did not. (4) Have students reached the desired outcomes? This question was answered "unhurriedly . . . only after the district administration had determined that a new . . . [curriculum] program was implemented as planned" (Romberg & Price, 1983, p. 179); standardized achievement tests were used.

Another version of systemic evaluation, one favored by the NSF's Teacher Enhancement Program, focuses on different program effects ". . . through appropriate assessment and documentation of activities . . . that will be useful in understanding the project and its effects and consequences" (National Science Foundation, 1989, pp. 11-12). Such an evaluation provides, in addition to demographic and background information on participants, information about different effects of the in-service education program on

- target teacher audiences, including increased content and/or pedagogical knowledge, increased enthusiasm, willingness to collaborate for improvement, readiness, and ability to provide leadership;
- outreach activities in schools for teacher participants and their peers and students; and
- participant institutions, including strengthened course offerings or degree requirements, increased allocation of resources, improved working relations.

In contrast to systemic evaluation, some evaluators recommend focused evaluation in which resources are specifically deployed to examine certain critical aspects of an in-service program. For example, the evaluation might focus on judgments by the teachers themselves about the effect of the in-service program, or researchers' measures of the effects of the program on teachers' behavior, or how teacher behaviors acquired during the in-service program affects students in classrooms (Yarger, 1982).

5.3.2 How Should the Program Be Evaluated?

Diversity abounds on the issue of how to evaluate in-service programs. Recommendations include randomized experiments (e.g., Ross, 1990), longitudinal causal modeling (e.g., Romberg & Price, 1983), pre- and post-program questionnaires and tests (e.g., Carlson, 1990), correlations between teacher behavior observations and student outcomes (e.g., Yarger, 1982), and qualitative descriptions of the program from the participants' perspectives (e.g., Lorenz, 1982). Weiss, Boyd, and Hessling (1990) catalogued the predominant methods used to evaluate in-service education in science and mathematics education based on their survey of NSF principal investigators. The results are provided in Table 5-2.[5] While each of the methods have a legitimate role to play in providing evaluative information on an in-service program, unfortunately testimony is all too often the sole source of such information.

Table 5-2

How In-Service Programs are Evaluated

Focus of evaluation	Method	Frequency of use
Teacher knowledge and confidence	Participant report of feelings and anecdotes through questionnaires, testimonials, or hearsay (e.g., principal investigator)	Frequent
	Pretest to posttest changes in knowledge and/or attitudes	Rare
Teacher instructional skill	Participant report of feeling and anecdotes through questionnaires, testimonials, or hearsay (e.g., principal investigator's report)	Frequent
	Systematic classroom observation	Rare
Teacher sense of profession (e.g., alleviate sense of isolation, create enthusiasm)	Participant report of feelings and anecdotes through questionnaires, testimonials, or hearsay (e.g, principal investigator's report)	Frequent
	Outside evaluation	Rare

SOURCE: Weiss, et al. (1990)

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[5] *Fitzsimmons et al. (1991) reached similar conclusions based on a survey of principal investigators.*

5.3.3 When Should the Program Be Evaluated?

Most evaluations do not ask, "Is this the right time for the particular type of evaluation being conducted?" The right time depends on the purpose of the evaluation. For example, if one wishes to select an in-service education program, a "forward-looking" evaluation has to be done before the selection decision is made. Until the program is fully implemented, formative evaluations seem more appropriate (cf. Fitzsimmons, et al., 1991; Knapp, et al., 1990; Romberg & Price, 1983). Summative evaluations, which look at outcomes or effects, seem appropriate once an in-service program has been up and running with the kinks worked out. Indeed, summative evaluation may not be able to detect effects if it is done immediately upon the close of training. For example, in the case of the Santa Barbara Instructional Technology Project described above, a substantial increase in effects was detected *between one and two years after the end of the project* (Copeland & de la Cruz, 1990). Nevertheless, funding agencies such as the NSF seek systemic, effects-based evaluations of in-service programs within the normal funding cycle, which is on average about three years from inception to completion (cf. Fitzsimmons, et al., 1991). Perhaps this is insufficient time for the program to be fully implemented and running smoothly.

5.3.4 Who Should Conduct the Evaluation?

Diversity of opinion also surrounds the question of who should conduct the evaluation. Should it be the program's principal investigator, a program staff member assigned responsibility for evaluation, or an outside evaluator? Perhaps the wisest answer to the question is to recognize that who the evaluator should be depends, in part, on the purpose of the evaluation, on the aspects of the program to be evaluated, and on the technical skills required to conduct the evaluation. For example, collecting case study and simple questionnaire data might very well provide insight into whether the program succeeded in meeting its goals and it might be carried out by project staff. But it does not provide comparative information, for example, to permit a selection from among alternative programs with similar goals. Moreover, evaluations intended to reflect the effects of an in-service program probably need a combination of in-house and external evaluators, budget permitting, to establish the independence and credibility of the findings. This common-sense notion is reflected in NSF project evaluations. Over the period from the inception of the NSF's Teacher Enhancement Program (TEP) in 1984 through 1989, the percentage of projects reporting evaluations jumped considerably. The use of outside evaluators by individual projects increased from 12.9 to 40.1 percent, corresponding to the increase in funds available to the TEP (Fitzsimmons, et al., 1991). In that same time, the percentage of projects using staff to carry out evaluation activities increased from 61.3 to 74.6 percent.

5.3.5 Who Cares About Program Evaluation?

At least three audiences can be identified: program developers, school district decision makers, and funding agency staff. Each have a different perspective and use for evaluation information. Project developers are interested in whether the in-service program is "working." School district decision makers are concerned with selecting a particular in-service program for their teachers. This audience is probably most interested in a rich description of the staff development program, along with, say, per-teacher cost and outcome information. Funding agency staff are concerned about documenting the nature of the program, participants served (especially minority teachers), and the direct (specific teacher behavior changes) and indirect (student behavior and achievement) effects of the program. At issue here are justifications for programs (e.g., to the U.S. Congress in the case of the NSF), the agency's impact on science education, and institutional learning about what works when funded.

The choice of a particular evaluation then, rests on the answers to these questions. In some cases hybrids may be needed to tailor the evaluation to local in-service education needs. Table 5-3 summarizes the foregoing discussion and provides a catalog of alternatives that might be considered in evaluating in-service projects. It presents a general characterization of evaluation types according to the purposes of the evaluation. The characterization also presents some general questions that differentiate the evaluation types: when should the information be obtained? What questions must be addressed? What methods might be used to obtain information? What should the evaluation report focus on?

The diversity of approaches to teacher enhancement, the diversity of opinions about evaluation, the diversity of program evaluation models (e.g., Cronbach, 1963; 1980; Scriven, 1973; 1991; Stake, 1967; Stufflebeam, 1973; 1983), and the diversity of evaluations conducted to examine in-service science education projects reflect several fundamental tenets about in-service program evaluation. First and foremost, the evaluation must be crafted to fit the nature of the in-service project and the most telling questions being asked about the project. Off-the-shelf evaluations are likely to provide a great deal of information of only tangential interest or

Table 5-3

Characteristics of the Three Types of Program Evaluations

Features	Forward-looking	Formative	Summative
Proposed use	Provide information for planning or selecting a program	Provide information for program improvement during its development and/or implementation	Provide information about the effectiveness of the program in achieving its objectives, how it compares with other alternatives, and its impact
When the information must be obtained	Before program implementation	During program development and implementation	When program is completely implemented and operational
What questions must be addressed	• Do program goals meet consumer needs? • What is the documented evidence of the program's real or potential effectiveness? • Is the program likely to have merit?	• How well do program components achieve their goals? • What components of the program have to be modified or replaced to improve the program?	• Were the program goals achieved? • Does the program represent a significant advance in comparison with some competing alternatives? • Does the program's effectiveness justify its expenses?
Methods for obtaining evaluative information	• Checklists • Cost analyses • Reviews of literature • Interviews • Analyses of documents	• Performance tests • Experiments • Surveys • Questionnaires • Observation • Interviews • Analyses of documents	• Performance tests • Experiments • Records • Questionnaires • Cost-benefit analyses • Observation • Interviews • Analyses of documents
Focus of the evaluation report	• Match of program and consumer need • Resources needed for implementation	• Description of program activities and materials • Description of the program's components modified or dropped and reasons for such modification and deletion	• Evidence of program outcomes • Cost of program acquisition, maintenance, and operation • Evidence about advantages of the program in comparison with other programs with the same goals

utility. Second, questions addressed in the evaluation will be driven by the stage of program development (preparation, implementation, follow-up) and the audience. The audience could consist of developers seeking to improve the project, funding agencies seeking to describe and justify current projects or new projects, or school districts seeking to decide between alternative in-service programs or seeking the most cost-effective one for local adoption. Third, the level of expertise required to carry out an evaluation varies with the type of evaluation employed. Interviews and simple questionnaires collected in posttest only or pretest-posttest designs provide limited information but are well within the reach of many; sophisticated experimental or longitudinal quantitative and qualitative evaluations provide for strong inferences but are within the reach of few.

5.4 Conclusion

Successful implementation of science education reform, with its focus on hands-on inquiry and socially constructed knowledge, necessitates changes in the teacher's role and the physical and social organization of the classroom. In-service education, then, plays a major role in the reform. Indeed, in-service education should serve as a model of the teaching and learning that is expected to take place when teachers are in their classrooms. It should provide teachers with the opportunity to construct both content and pedagogical knowledge, to practice the application of this knowledge, and to take responsibility for knowledge construction and application. Evaluation should go hand in hand with in-service science education programs, shedding light on the degree to which the program meets its intended purposes.

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PART THREE: IN-SERVICE EDUCATION IN MATHEMATICS

INTRODUCTION

Thomas Romberg, Thomas Cooney, and Penelope Peterson

The mathematical sciences education community in the United States has reached the conclusion that, compared with traditional school practice, "all students need to learn more, and often different, mathematics and that instruction in mathematics must be significantly revised" (National Council of Teachers of Mathematics [NCTM], 1989, p.1). A cross section of that community has developed a vision for reforming the school mathematics curriculum and for effective ways of teaching students within the context of such a curriculum. This vision is articulated in two documents, *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) and *Professional Standards for Teaching Mathematics* (NCTM, 1991). Our purpose in this part of the book is to share with those responsible for the development and implementation of teacher enhancement programs in mathematics some of the central themes and assumptions underlying the reform movement and implications these have for in-service education.

Central Themes

There are five themes underlying the shift in the teaching and learning of mathematics in school classrooms that emerge from the reform documents. Teacher enhancement programs need to acquaint teachers about the implications of these themes.

Knowledge. Rather than believing that knowing mathematics involves mastering a large collection of concepts and skills in some predetermined order, teachers and students need to see that knowing mathematics involves solving non-routine problems. Appropriate concepts and skills are developed as needed, however, to solve such problems. The chapter by Thomas A. Romberg describes some of the reasons that the content and organization of mathematics curricula need to be changed given this view of mathematics knowledge.

Work of Students. Rather than complete a predetermined set of exercises in a particular order, students need to explore problem situations, make conjectures, build reasoned arguments, and communicate with other students and their own teacher as they construct meaning from their experiences.

Work of Teachers. Rather than cover the pages of a mathematics text in an attempt to get students to work sets of exercises in the manner shown, teachers need to provide students with a rich set of problems, listen to how they think and attempt to solve those problems, probe their responses, and guide their thinking. Penelope Peterson's chapter elaborates on the connections between the work of students and teachers' instructional practices.

Technology. Rather than being bound by a textbook and working independently on paper-and-pencil worksheets following a daily pattern, students need to work on realistic problems with a local or global context, often in groups, for prolonged periods, with appropriate tools (manipulatives, calculators, or computers).

Professionalism. Rather than being isolated from other teachers, teachers need to share ideas and examples with other teachers in their schools and at professional meetings. The chapter by Thomas Cooney summarizes the implications of the reform movement for the professionalization of mathematics teachers.

A Different Form of Instruction

To illustrate the impact of these central themes on the nation's classrooms, we look here at an example from Whitnall High School in Greenfield, Wisconsin. Gail Burrill, the Chair of the Mathematics Department, describes what happened when she and six other members of her staff taught an experimental unit on "data visualization"[1] to several classes of algebra students at the start of the school year. According to the principles advocated in the *Standards*, the unit was designed to provide a structure in which students could develop the skills required to use critically the statistics presented by the media.

The *Standards* state that knowledge of statistics is necessary if students are to become intelligent consumers capable of making informed and critical decisions. Today, all of us encounter visual representations of data in newspapers and on television. The unit includes activities designed to teach students how to describe a data set numerically, represent data graphically, and examine representations of data critically. Using tables and graphs found in current newspapers and magazines, the unit examines presentations and conclusions about such issues as population demographics and presidential elections, the relation between education and income, and the relations between running speed and oxygen consumption, crime, and cholesterol. Note that this is new, but important, content that students in the 9th grade are expected "to know."

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[1] *A revision of the unit has now been published (de Lange & Verhage, 1992).*

Teaching such a unit is quite different (compared with usual classroom practice) for both teachers and students. To illustrate this, Burrill first contrasts the traditional method of teaching mathematics with teaching practices advocated in the *Standards*:

> The standard way of teaching in most of our math classrooms -- although we varied it and did a lot of group work -- was to begin a class by presenting the idea to the students, giving them several examples, and then assigning them some seatwork. During the seatwork, we would help them work out what we had told them to do. (Interview notes)

To teach materials aligned with the *Standards*, teachers must shift their teaching styles toward an emphasis on problem solving and away from a skills-based focus on computation. Burrill points out that students must also shift their focus, a change that is easier if teachers realize that students come to mathematics with some background knowledge.

> We try to capitalize on their prior knowledge as they approach and solve the problems. We work to expand what they know, but we start from their knowledge and experience, not just from what we think they ought to know. (Interview notes)

Some teachers felt insecure at the beginning of the unit. Teachers who had viewed themselves as teaching statistics at the outset of the trial began to view themselves in the next few weeks as helping students learn how to use statistics to solve problems. Suddenly, there were no right answers; instead, there were several possible solutions to problems. To help students learn to solve problems, teachers learned to probe students about their understanding, to listen to what students had to say, and finally to interpret students' explanations. Communication became an essential part of the classroom enterprise. Clearly, the "work of teachers" had changed.

Students had little difficulty adapting to the new materials and new ways of learning mathematics. While all students indicated they enjoyed the unit on data visualization, some did not view it as "real" mathematics. Students who flourished in mathematics classes that emphasized practice and replication found themselves challenged in new ways when working through the unit. Some who had been considered "poor in math" were able to succeed, and some who had been considered "good in math" suddenly found themselves less successful.

Students experienced some frustration as their teacher's behavior changed. One student remarked, "How can I do something if you don't tell me what to do?" Students who were used to taking shortcuts (such as searching for key words) to avoid reading questions found the shortcuts less useful, and students who were used to answering "yes" or "no" questions found they were now forced to justify their conclusions. The attitudes of students changed during the five-week trial. They increased their appreciation of common sense, discussion, and creativity, and they developed the view that mathematics is more than memorizing rules. In such an instructional environment, the "work of students" and the "technology" of the classroom had changed.

Parenthetically, Burrill admits that the new emphasis on writing in mathematics — which is fully argued in the NCTM *Standards* — is an unaccustomed practice for students and teachers alike.

> Today I felt like an English teacher. I read some inadequate responses to the class, asking the kids what they had learned. When I read the student's paragraph, I asked the class to tell me what they thought was going on. . . . Obviously, sometimes they couldn't tell me anything. The results were inconclusive, or the writer didn't tell what the results were or explain the source of the data. We spent a lot of time on this. The kids feel that they need to know how to communicate. Some of them do better than others. There are kids who resist writing in math, but they're getting better at it. (Interview notes)

The teachers also found they needed to share ideas with other teachers. Burrill found that before instruction began, teachers needed in-service sessions to grasp the philosophy and talk about what actually happens in the classroom. This must be followed by support sessions as the teachers work their way through the materials themselves. Then, while the unit was being taught:

> The department met every Monday for an hour or more and talked about what had happened in our classes, how we felt about where we were going. We brainstormed some solutions we might use as a department to make things easier for us. (Interview notes)

Rather than being isolated from one's fellow teachers, this kind of instruction demands that teachers share in a "professional manner" with others.

In summary, the following quotes from one of the teachers at Whitnall shows the changing role teachers had to deal with when teaching this unit.

> Many of the strategies we had used to help our students master manipulative skills were useless in the new environment. . . . The possibility that several points of view and, consequently, several answers, were reasonable is difficult to accept, especially when you have spent an average of 15 years rewarding thought processes that were identical to yours. . . . Our role was shifting from that of one who directs the thought processes of the students to one who reacts and guides their reasoning; it was not easy to resist telling students what to do or showing them how, but instead to ask leading questions. We had to listen to students, examine their work, and try to learn what they were thinking as they solved a problem. . . . Communication became an integral part of the classroom dynamics (de Lange, van Reeuwijk, Burrill, & Romberg, 1993, pp. 190-192).

Underlying Assumptions

Two assumptions underlie the following chapters that are relevant to teacher enhancement programs:

> ***Assumption 1:*** Change toward the vision of mathematics instruction based on these central themes and exemplified in the experience at Whitnall High School is critical.
>
> ***Assumption 2:*** Teachers are the key people in a position to make the needed changes.

Of course, associated with these assumptions is the realization that teachers will need new materials, means of assessment, administrative and public support, and most of all, opportunities for professional development. The implications for in-service education are profound. In particular, teachers will need more than additional mathematics courses. They will need help to develop professional self- confidence.

To achieve the empowerment of teachers as a first step in preparing them to be the leaders in school mathematics reform efforts is no easy task. In the design of in-service programs, teachers, in the same manner as their students, need to be treated as constructive learners. Their understandings and beliefs about mathematics, their conceptions of how learning occurs, the identification of barriers, and their views about the importance of listening to students may need to be challenged. But these challenges should be treated as problems to solve not as recipes to follow.

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6 LEARNING AND TEACHING MATHEMATICAL SCIENCES: IMPLICATIONS FOR IN-SERVICE PROGRAMS

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Prologue

One summer, my then five-year-old daughter, Elissa, accompanied me on a trip to Turku, Finland, where I was to present a paper on mathematics learning and teaching at the meeting of the European Association of Research on Learning and Instruction. I viewed this sojourn as a time to develop a closer relationship with my daughter and to try to understand more about her interests and ideas. Elissa viewed the trip as an opportunity to spend time on vacation alone with her mother and without her older brothers around. The night before I was to present my paper, Elissa and I were snugged down side by side in our twin beds in our hotel room, when suddenly Elissa burst forth with a torrent of questions. Her queries were embedded within a running monologue, but these struck me most:

> Why are there bad things in the world; why aren't there just good things?
>
> Why do people die?
>
> Isn't it interesting that numbers go on and on? That's called 'nfinity, isn't it, Mom?

Dumbfounded as I was, both by the sophistication of Elissa's questions and by the sense that these represented centuries-old fundamental human dilemmas, I struggled to respond. As Elissa's mother, I thought I should have answers, and I assumed that Elissa had asked these questions because she wanted answers from me. So, rather than listening and querying Elissa about her thinking on these ideas, I slipped immediately into my "teaching as telling" mode and told her my thinking. I gave her the Platonic argument that if bad didn't exist in the world, then people wouldn't be able to recognize good when they saw it. Unimpressed by this argument and rapidly losing interest in Plato's and my answers, Elissa soon drifted off to sleep while I was left to ponder Elissa's questions.

With Elissa's questions still on my mind, I went off to my conference session the next day where I was to present following a psychologist from the Max Planck Institute who had done a study of children's mathematics learning. I was listening intently to the psychologist's presentation when suddenly I was brought up short by her remark that she had found that it was "so difficult to get fourth and fifth grade children to understand abstract concepts like infinity." I wondered to myself, "Hmmm. Has she conversed with any five year old kids lately, and really listened to what they are thinking about?" Suddenly I wished that I had brought Elissa to the session with me to talk with the psychologist. As I had not, I said nothing to the psychologist, yet I kept on wondering about the sophisticated musings about the finite and the infinite suggested by Elissa's questions.

In September Elissa started first grade in a nearby elementary school in our upper-middle-class neighborhood. Education reform seems far removed from Elissa's classroom, where her teacher teaches reading, phonics, and decoding using basal readers and worksheets, and she teaches computation and mathematical procedures using the Comprehensive School Mathematics Program. During the second week of school, Elissa came home excited that her teacher had taught them to use the "minicomputer" — a paper abacus designed by mathematicians Georges and Frederique Papy. Elissa reported that her teacher had told the class that "they could show any number on the minicomputer." Turning to me, Elissa commented in a conspirational voice, "I know that's not exactly true because numbers go on and on." She understood that because numbers go on and on to infinity, it would take forever to show ever number on the minicomputer, and Elissa saw such a feat as not humanly possible in her teacher's lifetime. To my consternation, I learned from Elissa that she had not shared this understanding with her teacher or with the other students in her class. Although only in the first of many years of schooling, Elissa had learned already that it is inappropriate to question the teacher's statements or to share her real thinking and ideas.

Elissa and her teacher have come *to share a set of assumptions* about knowing and learning that reflect the way scholars and practitioners have conceived of the learning and teaching of mathematics for decades and perhaps even centuries (e.g., Cohen, 1988; Swetz, 1987):

> *Elissa enters her first grade class lacking important mathematical knowledge and understandings. The teacher already has this important mathematical knowledge and understanding and will transmit it to Elissa and the other first-graders through her teaching. Elissa will learn mathematics through drill and rote practice of computational procedures, working mostly individually and mostly through paper-and-pencil exercises and worksheets.*

6.1 Shifts in Assumptions about Learning

In the past decade, just as mathematical sciences educators have revised their notions of the mathematics curriculum (Romberg, this volume), so have psychologists and educational researchers revised their assumptions about human learning. Many of their ideas are not new and have evolved from ideas of Dewey, Piaget, and Vygotsky — psychologists whose writings have existed for decades, but whose views of learning have been obscured by other views of learning, such as those of Thorndike and other behaviorists (see, for example, Lagemann, 1989; Schoenfeld, 1992b).

These shifts in assumptions away from behaviorist views and toward alternative views underlie much of the rhetoric of contemporary mathematics education reform and the visions laid out in the National Council of Teachers of Mathematics (NCTM) *Standards* (1989, 1991). New visions of mathematics learning and teaching are couched in terms of "constructed knowledge" (National Research Council, 1990) or learners constructing their own mathematical understandings (National Research Council, 1989, pp. 58-59). In *Science for All Americans*, Rutherford and Ahlgren assert that "people have to construct their own meaning regardless of how clearly teachers or books tell them things" (1990, p. 186).

Although shifts in assumptions about learning may be clear to many scholars in the mathematical sciences education community, such assumptions are not always apparent to teachers and teacher educators, who have their own sets of understandings and beliefs within which they work. Also, researchers do not share a unified perspective, and within the mathematics and science education communities, debate continues among different points of view (see Confrey, 1990; Davis, Maher & Noddings, 1990; Smith, diSessa, & Roschelle, 1991; Nickerson, 1992 for expositions of some of these views on the mathematical sciences). Researchers who share certain assumptions, questions, methods, and explanations form scholarly communities of discourse in which they share their developing knowledge and understandings through published writings, presentations, and conversations at scholarly meetings, and most recently through conversations over electronic networks. These communities of inquiry have been called "invisible colleges" — by Sir Isaac Newton in the seventeenth century, and by contemporary researchers studying the sociology of knowledge (Crane, 1972), and by Kuhn (1970).

In the past the members of the science and mathematics education communities have not always shared common assumptions and understandings, yet the reform movement aims to relate mathematics to science and change the ways they are taught in schools. Science and mathematics are inextricably interwoven in the work of scientists and in the practice of life. Considerations of curriculum, learning and teaching, and education of teachers must consider this integration of science and mathematics as well.

In this chapter I focus on four key assumptions about learning that are coming to be shared by many members of the mathematical sciences education community (see Greeno, 1989; Schoenfeld, 1992 for discussions of a similar set of assumptions):

- Humans are knowledgeable learners.
- Learning involves the negotiation of shared meaning.
- Knowing is situated or contextualized.
- Assumptions about knowledge influence learning.

These represent shifts from traditional assumptions and a departure from the earlier, dominant behaviorist view. These four assumptions are central to contemporary theory, research, policy, and practice in mathematical sciences education. In the following discussion, I examine each of them separately. Yet, through this explication I hope to reveal ways in which these assumptions are related.

6.2 Humans Are Knowledgeable Learners

In the 1970s and 1980s, psychologists interviewing children and studying the development of children's mathematical knowledge became increasingly impressed by the mathematical knowledge that young children bring with them to school. In earlier decades scholars had assumed a "tabula rasa" view of children's minds when they enter school, and had been preoccupied with children's lack of knowledge and readiness. But in interviewing young children, scholars became increasingly intrigued with trying to understand children's thinking. In their studies these researchers assumed that mathematical knowledge — like all knowledge — is not directly absorbed but is created by each individual. While consistent with the theory of Jean Piaget, this view did not necessarily imply either a stage theory or the logical determinism of orthodox Piagetian theory (Resnick, 1989, p. 162). As a result of their interviews with children, these researchers concluded that "children do invent original solutions to mathematics problems" (Davis, 1984, p. 16).

From these studies of children's mathematical knowledge, researchers developed frameworks of children's mathematical knowledge in several domains, including addition/subtraction, rational numbers, and multiplication/division (see, for example, Lesh & Landau, 1983; Romberg & Carpenter, 1986; Riley & Greeno, 1988). One way that researchers have thought about this mathematical knowledge is to argue that children's informal knowledge could serve as a basis on which teachers might build their mathematics curriculum (Fennema, Carpenter, & Peterson, 1989; Ginsburg & Yamamoto, 1986). For example, by building on children's own counting strategies and by encouraging children to use counters, fingers, and other mathematical tools, young children are able to solve many addition and subtraction word problems that adults would previously have thought to be too difficult for a child and would require a school-taught algorithm.

Yet another way scholars have thought about the substantial mathematical knowledge, understandings, and beliefs that children bring to the classroom is to see children as having lenses or filters through which they interpret and understand the new (see, for example, von Glaserfeld, 1987). Children, like all people, "continually try to understand and think about the new in terms of what they already know" (Glaser, 1984, p. 100). One implication of this is that when teachers see children as creating knowledge, filling in gaps, and interpreting in order to understand, they then begin to view children's "wrong" mathematics answers in a new light. Mathematical "errors" are no longer mistakes — something to be gotten rid of — but indications of children's developing understandings that provide insight into how the child is trying to make sense of something. A second implication is that teachers need to reconsider when and why they "teach the rules, 'tricks of the trade' that get rid of 'errors,' because they might be getting rid of the clues they need in order to follow their students' thinking" (Resnick, 1988-89, p. 15).

According to the above view, learning is assumed to be individual and cognitive. But this view has been broadened to include the assumption that learning is social and cultural as well (Resnick, 1987; Greeno, 1990; Lave, 1990).

Cobb, Yackel, and Wood (1992) argue that mathematics educators need to move beyond a representational view of the mind and assume that mathematics learning is both an individual, creative activity and a communal, social practice. Similarly, Davis, Maher, and Noddings assume that "learners have to construct their own knowledge — individually and collectively. Each learner has a tool kit of conceptions and skills with which he or she must construct knowledge to solve problems presented by the environment. The role of the community — other learners and the teacher — is to provide the setting, pose the challenges, and offer the support that will encourage mathematical construction" (1990, p. 3)

6.3 A Case of Children as Learners in a Classroom Community

We are just beginning to learn what children are capable of learning in a social context within their own mathematics education community. Ball (1993; 1991) describes an example in which a student in a third grade mathematics class, Sean, conjectured that numbers can be "both odd and even." As the classroom discourse unfolded, Sean explained what he meant, in response to queries from his fellow students. The classroom discourse that followed is shown in the sidebar.

Excerpt from the classroom discourse in Deborah Ball's third grade mathematics class, illustrating children's mathematical invention and knowledge in a social context

(from Ball, 1991, 1993).

Sean: Um . . . 2, 4, 6 . . . 6 can be odd or even . . . 8

Students: No . . . !

Temba: Prove it to us that it can be odd. Prove it to us.

Sean: Okay. (He goes to the board.) Well, see, there's 2 (he draws) number 2 over here, put that there. Put this here. There's 2, 2, and 2. And that would make 6.

00 ¦ 00 ¦ 00

Temba: I know, which is even!

Mei: I think I know what he's saying . . . I think what he's saying is that you have three groups of 2. And 3 is an odd number so 6 can be an odd number and a even number.

Ball: Do other people agree with that? Is that what you're saying, Sean?

Sean: Yeah.

Ball: Okay, do other people agree with him? (pause) Mei, you disagree with that?

Mei: Yeah, I disagree with that because it's not according to like . . . how many groups it is. Let's say I have -- (pause). Let's see. If you call 6 an odd number, why don't -- (pause) let's see -- (pause) let's see -- 10 . . . 1, 2 . . . (draws circles on the board) and here are ten circles. And then you would split them. Let's say I wanted to split them by twos . . . one, two, three, four, five. (she draws)

00 ¦ 00 ¦ 00 ¦ 00 ¦ 00

Then why do you not call 10 an odd number and an even number, or why don't you call other numbers an odd number and an even number?

Sean: I didn't think of it that way. Thank you for bringing it up, so -- I say it's -- 10 can be an odd and an even.

Mei: (with some agitation) What about other numbers? Like, if you keep on going on like that and you say that other numbers are odd and even maybe we'll end it up with all numbers are odd and even. Then it won't make sense that all numbers should be odd and even, because if all numbers were odd and even, we wouldn't be even having this discussion!

In this episode Sean reveals his discovery of a new number that can be "both odd and even." Through Sean's explanations we learn that what Sean has discovered is that there are some numbers that have factors that are both odd and even. Later in the class discussion the teacher, Deborah Ball, legitimized the new knowledge that Sean had introduced by pointing out that he had created another kind of number that they hadn't known about before and suggested that the class call them "Sean numbers." Although Ms. Ball had never heard of "Sean numbers" — numbers composed of an odd number of groups of two — after Sean "discovered" them in class, she subsequently found out that Greek mathematicians had discovered this kind of number and worked with it centuries ago.[1]

The creation of Sean numbers by children working within a discourse community is important because it represents an "existence proof" of the kind of mathematical knowing and learning that children can engage in within the social context of an actual classroom. Until recently, studies of children's knowledge have been of individual children interviewed one at a time by researchers outside the classroom context (see, for example, Riley & Greeno, 1988). What we learn from the Sean numbers example in Deborah Ball's classroom is that earlier studies may underestimate significantly what children know and understand when knowledge is shared and constructed in the context of a community of learners. Attention to the social in learning means that access to knowledge broadens: an individual lens is expanded to include additional sources of knowledge provided by other people and through tools and technology; the development of knowledge is broadened and deepened with the community of learners; and the influences of increased social discourse, access to others' knowledge, and collaboration work to create new knowledge.

6.4 Learning Involves the Negotiation of Shared Meaning

If learning is viewed as social and communal as well as individual and constructive, then the question of how meaning comes to be shared becomes important, as does the role that discourse comes to play in the development of shared meaning. Researchers are increasingly focusing on the potential of conversational patterns of discourse as compared with the lecture-recitation pattern of discourse that has traditionally predominated in classrooms (see, for example, Cazden, 1986).

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[1] *Janine Remillard, a graduate student and colleague of Dr. Ball, was the person who called this to her attention. Ms. Remillard found in D.E. Smith's* History of Mathematics, Vol. II, *the following:*

> *Euclid [studied] "even-times-even numbers," "even-times-odd numbers," and "odd-times-odd numbers." His definitions of the first two differ from those given by Nicomachus (c. 100) and other writers. . . . How far back these ideas go in Greek arithmetic is unknown, for they were doubtless transmitted orally long before they were committed to writing. (p. 18).*

Dr. Harvey Davis, of the mathematics department at Michigan State University, confirmed this finding and indicated further that both Plato and the neo-Pythagoreans had also worked with "Sean-type" numbers, i.e., numbers produced by multiplying 2 by an odd number, resulting in "an odd number of groups of 2."

Tharp and Gallimore studied the classroom discourse created by teachers and students. They assert that "instructional conversation is the medium, the occasion, the instrument, for rousing the mind to life" (1988, p. 109). Building on the work of Vygotsky, Tharp and Gallimore discuss the role of conversation in assisting learning: They assume that assistance is provided by a more-expert other such as a teacher, adult, or more-expert peer. In this sense an instructional conversation differs from an ordinary conversation. Participants in an ordinary conversation would not necessarily assume that one of them was more or less knowledgeable than the other. An ordinary conversation is also typically less directed and goal-oriented than an instructional conversation.

In mathematics and science education, students need to learn to reason within the discourses of mathematics and science. For example, Wood, Cobb and Yackel (1992) state that in learning mathematics, the essence of the discourse is uniquely different from ordinary conversation:

> Students partake in a form of argumentation in which the meaning for mathematics is expected to be logically consistent. Students are obligated to explain and, when asked, justify their interpretations and solution methods to others. The students are expected to listen, make sense of the explanation, and ask for clarification. Participating in this form of discourse creates opportunities to learn that occur because students are engaged in negotiating mathematical meaning. In this situation, children not only engage in talk in which they construct individual ideas about mathematical relationships, but they also participate in the communal activity of doing mathematics. (Wood, Cobb & Yackel, 1992, p. 179)

Conceptualized as a discourse, scientific literacy is "a socially and culturally produced way of thinking and knowing, with its own ways of talking, reasoning, and acting; its own norms, beliefs, and values; its own institutions; its shared history; and even its shared methodologies" (Rosebery, Warren, & Conant, 1992, p. 65). To become scientifically literate, then, children need to learn to use language, to think, and to act as members of a scientific community. Anderson and Palinscar (1992) have taken this approach in their work on the development of scientific literacy through collaborative problem solving in racially and culturally diverse middle school classrooms. Within the same framework, Rosebery, Warren, and Conant (1992) describe the learning of language-minority students who participated in a collaborative inquiry approach to science called "Cheche Konnen" ("search for knowledge" in Haitian Creole). In Cheche Konnen, collaborative inquiry is interdisciplinary. Mathematics and language are seen as essential tools of scientific inquiry. Mathematics contributes to students' scientific sense making as a tool to be used in data collection and analysis activities (e.g., measurement, statistics, and graphical analysis and representation).

6.5 A Case of Learning as Mutual Construction of Knowledge

Jeremy Roschelle (1992) describes a case of mutual construction of knowledge through collaborative, conversational interaction between two high school students, Carol and Dana, who interact within a computer microworld ("the Envisioning Machine") that provides a simulation of velocity and acceleration. The students had not yet studied physics but had studied vector addition in their Algebra II class. In a detailed analysis of the interactions of these two students, Roschelle shows how Carol and Dana interact cooperatively to construct an understanding of acceleration that approximates the scientific meaning of acceleration ("the derivative of velocity with respect to time"). Working within a computer microworld designed by Roschelle (1990), the students must manipulate the position, velocity, and acceleration of a particle so that it makes the same motion as a ball does. The vectors attached to the particle present the Newtonian notations for velocity and acceleration, and the ball presents a familiar observable motion. In this particular case Roschelle had set the correct initial position and velocity for the students, so they only manipulated acceleration. In a larger study Roschelle found that students who constructed a scientifically compatible explanation of acceleration did so by moving from an explanation of "acceleration pulls the particle" to "acceleration pulls the tip of the velocity vector." In this case Carol and Dana mutually construct such an explanation through a process that Roschelle describes as "simultaneously cognitive and social" (Roschelle, 1992, p. 270).

Roschelle argues that the "crux of learning through collaborating is convergence. . . . Followers of Vygotsky who investigate collaboration have tended to see collaboration as scaffolding and appropriation — scaffolding by a more expert peer, and appropriation by a less expert peer . . . . Piaget and his followers tended to see collaboration as producing individual cognitive conflict — disequalibrium drives conceptual change. . . . In this case study mutual construction of knowledge was a more apparent feature of students' interaction than was cognitive conflict or scaffolding" (Roschelle, in press, p. 247-248). For example, in one episode, shown in the sidebar, Roschelle (1992) shows how Carol and Dana work to converge on a shared interpretation of acceleration.

Not only does the episode in the sidebar portray how Carol and Dana mutually construct knowledge, it also shows how they negotiate meaning. What is revealed is how language is "indexical" and meaning is dependent on situations. Dana's utterance, "So I'm saying, OK (long pause) right that's what I'm saying" is devoid of meaning if taken out of the situation and the sequence of actions. Yet, within the situation and the sequence of events, Dana's words were filled with meaning because at Dana's pause Carol tried a hypothetical acceleration and traced the predicted resultant velocity, thereby showing how knowing relates to, and is embedded within, the situation or context. Thus, Dana and Carol's knowing is contextualized or situated.

6.6 Knowing Is Situated or Contextualized

In *Actual Minds, Possible Worlds*, Jerome Bruner (1986) presents a compelling case for the notion that learners are actually acting in constructed worlds. An implication of this claim is that knowledge can only be understood within the frameworks, understandings, and assumptions that serve as the bases of evidential claims for what learners know.

Brown, Collins, and Duguid contend that knowing is "inextricably *situated* in the physical and social context of its acquisition and use. It cannot be extracted from these without being irretrievably transformed" (1988, p. 1). This assumption contrasts sharply with the conventional assumption in education that knowledge is self-contained and discrete and can be transferred from teacher to students independent of the situation in which the knowledge is to be used. If knowledge is assumed to be embedded within the physical and social world, then it becomes important to consider the situations in which learning occurs and the situations in which the students use what is learned. Brown, et al. therefore concluded that "authenticity in activity is paramount for learning if conceptual knowledge is not self-contained but, rather, if it is the product of and structured by the activity in which it is developed and deployed; if in short not just learning but knowledge itself is situated" (1988, p. 15).

In the classic study by Geoffrey Saxe (1988), the interdependence of cognition and context was revealed through the development of mathematical understanding in Brazilian child candy sellers. These children had little or no schooling, but they developed in their candy-selling practice a complex mathematics that contrasted with school mathematics and with the mathematics understanding of their non-candy-selling peers:

Episode from a case analysis of the mutual construction of an explanation of acceleration by two high school students, Carol and Dana

(from Roschelle, 1992)

Note: [ ] indicates overlapping talk; = indicates no interval between end of prior piece of talk and start of next piece of talk

Carol (C): So if we wanted to pull this [the Envisioning Machine velocity arrow] down to there [a vertical line]. We'd have to have this [acceleration] all the way around or something like that. (begins to set acceleration, but doesn't release mouse button; see Fig. A)

Dana (D): No 'cause wouldn't that make this [the Envisioning Machine velocity arrow] tip swing around to that [the Envisioning Machine acceleration arrow] tip and make that angle . . . (ambiguous gesture)

C: What angle? (aborts setting acceleration)

D: So I'm saying, OK =

C: = I bet if I leave it [the Envisioning Machine acceleration arrow] like that (releases acceleration as in Figure B) it's going to make this [resultant] angle=

D: = right that's what I'm saying.

C: So we're going to have to swing all the way down here.

D: Oh my God! It's all so much clearer now.

Figure A: Carol's original setting of acceleration

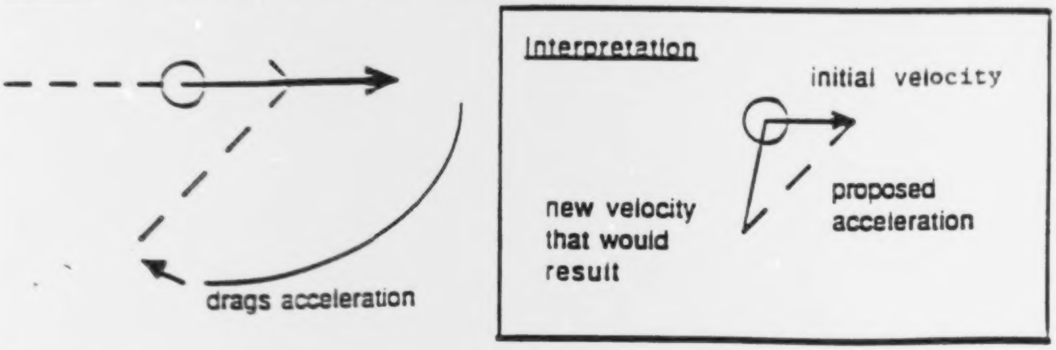
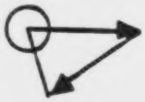


Figure B: The situation constructed for repairing meaning



> As sellers become involved in more complex problems of the [candy-selling] practice, their mathematical system becomes increasingly distinct from that of their nonselling peers. Sellers use their knowledge of bill values and relations between them to develop arithmetical problem-solving strategies that draw on the structure of the currency system. More and more, they construct concepts of ratio, knowledge forms linked to pricing conventions that emerged over the history of their practice. Thus, sellers develop a mathematics that is adapted to practice and, over time, manifests mathematical operations of increasing complexity and power (Saxe, 1988, p. 20).

Some scholars, such as Stanley Fish (1989) and philosopher of mathematics education Paul Ernest (1991), have gone so far as to assert that all knowledge claims (facts, truth, validity) are "intelligible and debatable" only within their context, paradigm, or community. They are merely the result of agreement among professional communities. Reality is the result of social processes accepted as normal in a specific context.

Building on the assumption that knowledge is situated or contextualized, scholars in the mathematical sciences education community have invented new worlds and contexts within which students can traverse mathematical and scientific territory, interact to solve problems, and engage in mathematical or scientific discourse. Examples are the scientific discourse communities constructed by Anderson and Palincsar (1992), Palincsar, Anderson, and David (1993), and Rosebery, et al. (1992) and the mathematical discourse communities created by Lampert (1990a, 1990b), Deborah Ball (1993; 1991), and Schoenfeld (1985) in their mathematics classrooms. For example, Ball and her students created a classroom context in which "Sean numbers" became a valid kind of number accepted and understood by all members of the classroom community. Another such example is the learning partnership that Carol and Dana created within the "Envisioning Machine" microworld in which they were able to coconstruct an explanation for acceleration that was meaningful to them.

Researchers have created other computer software programs, such as *Geometric Supposers* (Schwartz, Yerushalmy, & Education Development Center, 1985-1987), that are potentially rich contexts for learning mathematics. *Geometric Supposers* is intended to serve as a context for teachers and students to "construct knowledge of geometry inductively, developing conjectures and testing them empirically" (Wiske & Houde, 1988, p. 1). This software program allows the user to construct geometric figures, draw additional elements, measure entities, and compute relationships among quantities.

In addition to assuming that knowledge is contextualized and created within a community, the above researchers assume that schools and teachers should represent mathematical knowledge differently than it has traditionally been represented in schools. While the general public, including teachers, parents, and school children, continue to view mathematical knowledge as precise, rigorous, and certain, many philosophers and mathematicians view mathematical knowledge as dynamic, creative, and uncertain (Kline, 1980; Lakatos, 1976; Hersh, 1986; Grabinier, 1986). Chazan has described how *Geometric Supposers* is used to represent mathematical knowledge differently than it is represented in traditional classrooms in order to capture the "quasi-empirical" view of mathematics and the social nature of the validity of a proof.

> In traditional geometry instruction, students are given true statements and are asked to write proofs for these statements. It is clear to students that the statements are true (otherwise they would not be asked to prove them) and that their teacher knows how to prove them. In contrast, the *Geometric Supposers* can be used in an exploratory approach where teachers pose problems to students and ask them to investigate a given geometric construction and make conjectures about all the particular drawings which can be created by this construction. These student-generated conjectures are then the statements which students are asked to prove . . . . Students can use quasi-empirical verification, they can accept as true statements for which they can find no counter-examples . . . . When deductive proofs are first introduced, there could be less of an emphasis on having students write proofs and more emphasis on critiquing proofs. Students can be asked to try to find counter-examples to textbook proofs and to expose assumptions not presented in the proof . . . The social nature of postulates can also be emphasized (1990, pp. 19-20).

For researcher-teacher Chazan, *what* one comes to know in a learning situation can not be separated *from the way* one comes to know it. In other words, to understand mathematics as uncertain, dynamic, and a tool for solving problems, students must experience mathematics as beautiful but uncertain, understand that solving mathematical problems is truly problematic, and view mathematical proof as truly subject to dispute or verification.

In a final chapter of his 1986 book, Jerome Bruner took up this issue and concluded that he did not "for a minute believe that one can teach even mathematics or physics without transmitting a sense of stance toward nature and the use of mind. One cannot avoid committing oneself, given the nature of natural language, to a stance as to whether something is say, a 'fact' or the 'consequence of a conjecture'" (p. 128).

6.7 Learners' Assumptions about Knowledge Influence Their Learning

But what do learners' beliefs about learning and knowledge have to do with learning mathematical sciences? Many would answer "a lot," as they are coming to believe that understanding learners' epistemological beliefs are crucial to understanding what, why, and how students learn in science and mathematics classrooms.

Bereiter and Scardamalia summarized their expectations for why students' theories of knowledge are important this way:

> To the extent that students take an active role in learning, their own theories of what knowledge consists of and how it is acquired can be expected to matter. To take a simple example, even though the teacher may conceive of learning as consisting of much more than memorization of facts, the student might nevertheless conceive of it that way and this can be expected to have an influence on learning . . . . If, furthermore, the teacher handles classroom activities and testing so that memorizing facts turns out to be a successful way of getting along, this can be expected to further influence how students learn (1989, p. 367).

In pondering the importance of learners' personal and social epistemologies, Greeno (1989) reviewed research by Dweck and Leggett (1988) and by Belenky, Clinchy, Goldberger, and Tarule (1986) that showed that individuals and groups use their epistemologies to characterize and shape their intellectual activities. He concluded that, "recent research evidence shows that individuals have implicit theories of intelligence, knowing, and learning that influence the fundamental nature of the activities of knowing and learning" (1989, p. 136). The Nobel prize-winning physicist, Richard Feynman, is a good case in point.

6.8 A Case of the Power of Personal Epistemologies on Learning

In a volume of reminiscences about his life, Feynman (1985) offered some intriguing glimpses into his own thinking and learning. He also revealed something about his own personal epistemologies and assumptions about learning and his astonishment at discovering that others did not share these assumptions.

In his first chapter, Feynman invited the reader to think about how he, Feynman, learned mathematics. He recalled how in high school he invented problems and theorems. He posed problems to himself such as the following: "There's a flagpole, and there's a rope that comes down from the top. When you hold the rope straight down, it's three feet longer than the pole, and when you pull the rope out tight, it's five feet from the base of the pole. How high is the pole?" (1985, p. 11).

Feynman developed some equations for solving problems like the above and as a result, "noticed some connection — perhaps it was $\sin^2 + \cos^2 = 1$ — that reminded me of trigonometry" (p. 11). A few years earlier, when he was eleven or twelve, he had checked out a book on trigonometry from the library. He remembered only that trigonometry had something to do with sines and cosines, so he began to work out all the relations by drawing triangles, and each one he proved himself. Later when Feynman studied trigonometry in school, he still had his notes, and he compared them with the demonstrations in the book. He found that sometimes his way was more clever than the text author's and sometimes not. But this example reveals something important about Feynman's own stance toward knowledge which seems related to the brilliant and adventurous scientific thinker that he became.

How did Feynman "know" when he "knew" something, and what was "knowledge" to him? One answer is provided by Feynman's own description of an incident in his later life, when he questioned a theory of neutron-proton coupling. He asserted that he never paid any attention to anything by "experts": he calculated or figured out everything himself.

Interestingly, not only did Feynman make great discoveries in physics, but also he discovered that others did not share his own assumptions about knowledge and learning, and he found that puzzling. As he told it:

> When he was at MIT, a fellow joker in his mechanical drawing class picked up a French curve (a piece of plastic for drawing smooth curves) and wondered aloud whether the curves on the thing had some special formula. Feynman thought for a moment and then said, 'Sure they do. The curves are very special curves. Lemme show ya.' He picked up the French curve and began to turn it as he continued. 'The French curve is made so that at the lowest point on each curve, no matter how you turn it, the tangent is horizontal.' He was astonished when all the guys in the class began examining their French curves, holding their pencils up to it and the lowest point, and discovering that, sure enough, the tangent is horizontal. They were all excited by this discovery — even though they had already gone through a certain amount of calculus and had already "learned" that the derivative (tangent) of the minimum (lowest point) of any curve is zero (horizontal). They didn't put two and two together. They didn't even know what they 'knew'." Feynman puzzled about this and admitted: "I don't know what's the matter with people: they don't learn by understanding; they learn by some other way — by rote or something" (Feynman, 1985, p. 23).

Typical student beliefs tend to be much more like those of the MIT students than those of Richard Feynman. Table 6-1 shows a list created by Schoenfeld (1992) of the typical beliefs that students have about the nature of mathematics. Typical student beliefs contrast with those of Feynman, who viewed knowledge as capable of revision and as changing and growing. Feynman saw the responsibility for knowing and understanding as residing with the learner — the learner creates knowledge rather than receives it. In the end, the learner is the one who learns or does not learn: the teacher cannot do it for him. Moreover, there are multiple ways of solving mathematical problems, not just one right way. Discovery, invention, and verification are essential processes in mathematics, and mathematics can be best understood by rediscovering its ideas.

Table 6-1

Typical Student Beliefs about the Nature of Mathematics
(from Schoenfeld, 1992, p. 359)

Mathematics problems have one and only one right answer.

There is only one correct way to solve any mathematics problem — usually the rule the teacher has most recently demonstrated in class.

Ordinary students cannot be expected to understand mathematics: they expect simply to memorize it and apply what they have learned mechanically and without understanding.

Mathematics is a solitary activity, done by individuals in isolation.

Students who have understood the mathematics they have studied will be able to solve any assigned problem in five minutes or less.

The mathematics learned in school has little or nothing to do with the real world.

Formal proof is irrelevant to processes of discovery or invention.

An important corollary is that not only do students' beliefs have powerful influences on their learning, but also these beliefs are influenced and shaped by the contexts in which students learn. Teachers have beliefs about mathematics, knowledge, and pedagogy that play out in their mathematics instruction (Cooney, 1985; Schoenfeld, 1992). We turn now to a consideration of this issue.

6.9 What Might These Revised Assumptions Mean for Teaching?

The above assumptions represent scholars' revised assumptions about learning. What do these revised assumptions mean for teachers and teaching? We can illustrate what they might mean for teachers and teaching by analyzing the mathematics teaching practice of a first-grade mathematics teacher, Annie Keith, and examining the revised assumptions about mathematics learning that underlie her practice.

Annie Keith is intimately familiar with both *NCTM Standards* documents. Her thinking and practice have developed over the last six years, as she was one of the original teachers in a National Science Foundation-sponsored research and teacher enhancement project on Cognitively Guided Instruction (CGI) (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Peterson, Fennema, & Carpenter, 1991). For the past two years, Annie has been serving as a mentor teacher on the CGI Project as the researchers are attempting to extend the principles of CGI to the second and third grade curriculum (Carpenter, Fennema, & Franke, 1992). The CGI project directors' major thesis is that children enter school with a great deal of informal and intuitive knowledge of mathematics that can serve as the basis for developing much of the formal mathematics covered by the primary school curriculum. They work with teachers and provide them with content frameworks of children's mathematical solution strategies and problem types. They help teachers understand this knowledge, give teachers an opportunity to think about how to use this knowledge in their classrooms, and then encourage teachers to reflect on what happens as a result of trying to use this knowledge (Peterson, Fennema, & Carpenter, 1991).

The story of Annie Keith's learning and how she came to create her current mathematics practice are explored by me elsewhere (Peterson, 1994) and by Ellen Ansell whose dissertation is a year-long case study of Annie's mathematics teaching and learning (Ansell, in preparation). In the following section I focus on the mathematics learning and teaching as enacted in Annie Keith's practice on a given day and the assumptions underlying that practice.

6.10 Annie Keith's Mathematics Classroom

Every day, Annie Keith teaches mathematics to her first grade class at John Muir Elementary School from about 8:30 to 10:30 in the morning. The class starts the day with a meeting or whole-class conversation, with students sitting on the rug. On this particular day, a Thursday morning in March 1992, the 20 children were gathered on the rug in the meeting area. Thirteen of the children were Caucasian; five, African-American; one, Hispanic; and one, Egyptian. Twelve were boys, eight, girls. After taking attendance and the lunch count, Annie asked one of the students to count the sticks representing students who were going to eat a hot lunch. One of the boys counted the hot lunch sticks and concluded that there were seven. Annie asked, "How do you know it's seven?" The boy then counted the sticks one at a time, counting aloud as he did so. Turning to the class, Annie asked the children if they thought it was seven, and the class counted aloud together as the boy put the sticks down on the rug one at a time. At that point Peter piped up and said that they would need one more to make eight, "'Cuz after the 7 comes 8. You have to have two 4s to make 8."

In reply, Annie queried: "Does it help sometimes to know some of these facts — some of these doubles — about some numbers to help you solve other things?" The class responded, "Yes." And when Annie asked, "What do you mean, Erica?" Erica suggested that "Two is an even number, and this is an even number (she showed two fingers on her right hand) so if you put two together (she showed two more fingers on her right hand) that would make 4, so this would be an even number. And 8 would be an even number if you put another four again" (she showed four fingers on each hand).

Erica's remark opened up the door for a conversation that lasted nearly forty minutes, in which the students and their teacher traversed territory that included odd and even numbers, positive and negative numbers, 0 and negative 0. The following selection (see sidebar)[2] came midway through the discussion, when Erica returned the conversation to the question of whether there was a negative 0 or not by piping up, "On the number chart there's not a 0 negative." (Erica was referring to the number line on the wall that extended from −20 to 100.)

Following up on Erica's remark and realizing that she was responding to an idea that Daniel put forth earlier, Annie queried, "Daniel, did you hear what Erica's first comment was, because I think that is kinda aimed at you?" Annie asked Erica to tell Daniel what she meant, and Erica did this. Then Annie asked "Daniel, what are you thinking about that?" The conversation is reproduced in the sidebar.

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[2] *This transcription is from a videotape of Keith's class taken by Susan Baker, a CGI project staff person, and sent to me by Tom Carpenter. This videotape constitutes data being collected by the CGI researchers, as part of their NSF-funded project. My analysis is in no way intended to substitute for or supplant their own analyses of these data.*

Conversing about Negative 0

Annie: Hmmm. What about that idea of 0? She doesn't agree. She says there is just 0, not 0 and negative 0. What do you think about her comment?

Daniel: I think I agree with Alex -- because if 0 is odd, then 1 would be even. There has to be a starting for negatives too.

Annie: So you're thinking that 0 is an even number? So you're thinking there's a 0 and a negative 0?

Daniel: Yeah, I would say that.

Annie: Do you think there's a 0 and a negative 0?

Peter: Yeah. Before we didn't know about the negatives, 0 was really like a starting. But now that we know about them, there has to be a starting point for negatives too.

Alex: But then we'd have to keep on counting 0 and negative 0.

Peter: No, there is only going to be one of each.

Annie: Erica, I think you need to come and listen to this 'cuz I think we need you in on this conversation. Let me recap this: Peter you think there is a 0 and a negative 0. Erica, you don't think there is a negative 0. Why not?

Erica: Because there's not.

Annie: (to another girl who shook her head "no") You don't think there's a negative 0.

Other students: Me either.

Annie: Let's listen to some of what you guys are thinking about it.

Erica: Because it doesn't go "negative 0, 0, 1, 2, 3."

Annie: What does it do?

Erica: It just goes "1, 2, 3, 4, 5, 6, 7, 8, 9."

Annie: So going up on the positive side it goes like this. Then what happens on the negative side?

Erica: It goes negative 1, negative 2, negative 3. Maybe the number chart on the negative side isn't right, but I still don't think there is a negative 0.

Annie drew the following number line on the board as Erica explained it:

<-------------->
-3 -2 -1 0 1 2 3

Annie: So you don't think it goes 0, negative 0, negative 1? Hmmm. Somebody else, what do you think about this idea right here about 0 or negative 0?

Hannah: I don't think there is a negative 0 because if it went 0, negative 0, there would just be like two 0s in a row.

Alex: And the 1s there would have to be two rows, the 2s would have to be two rows . . .

Annie: So you're thinking if it went like this (drew a new number line on board) and like this (drew on board) this would be a negative 1 and a positive 1, 2. So you're thinking that wouldn't....?

Annie drew the number line on the board as she thought Alex saw it:

<------------------->
-3 -2 -1 -0 0 1 2 3 4

Alex: Yeah, that might be it because there would be one 0 for each set. One 0 for that set (pointed to the negative numbers) and one 0 for that set (pointed to the positive numbers).

Annie: Erica, you made a comment, you thought that 0 was a . . . (pause)?

Erica: A divider.

Annie: A divider. Can you elaborate a little more on that? What do you mean?

Conversing about Negative 0 (continued)

Erica: *If you had ten numbers, then you put a 0, then you would need one more in order to make 10. And then if you need another one, you would need two more to make 10. If you count the 0s in it, you would have to count the other 1s to get the other 0s. (While Erica spoke, Annie interspersed with "OK" and "Hmmm.")*

Annie: *So how does this 0 act as a divider? What does it divide?*

Erica: *It divides the negatives right here and the positive numbers. (Erica went to the board and pointed to show this.)*

Annie: *Oh, you're thinking 0 is kinda like a . . .*

Heather: *Which are the positives?*

Annie: *Which are the positive numbers?*

Erica: *(pointed as she said this) This is a positive number because it doesn't have this (pointed to a negative sign of one of the numbers on the number line) or else it would be not really a positive number — a negative number. Then if you had a negative 0, then this wouldn't be a divider, and this would be a positive, and this would be a negative.*

Annie: *Hmmm.*

Mathematics learning in Ms. Keith's classroom differs from mathematics learning in traditional first grade classrooms because Ms.Keith holds different assumptions about children's learning than teachers have traditionally held. These differences are related to the ways that Annie conceives of mathematical knowledge, learners' knowledge, the learning context, and the classroom discourse. These assumptions about learning are related to key aspects in the vision of mathematics teaching outlined by the *NCTM Professional Teaching Standards* (1991).

6.11 Assumptions about Knowing and Mathematical Knowledge

What is mathematics? In the field of mathematics, historians and philosophers of mathematics have shown that knowledge is changing and growing. In Ms. Keith's classroom mathematical knowledge is changing and growing as well.

In the episode reported in the sidebar, Annie's children come up with several provocative ideas. One is the idea of "0 as a divider." Although this idea is explored only superficially during the course of the discussion, it seems that at least one of the children, Erica, might be wrestling with ideas of place value in her thinking about the use of 0. Another idea is Daniel's conjecture that there is a "negative 0" because 0 is the starting point for positive numbers, and "there has to be a starting point for negatives too." The children pursue this idea vigorously, bringing up arguments and justifications for their assertions on either side of the question — there is a negative 0 or there is not a negative 0. The class period ends with no clear resolution, but the implication is that the students will continue to think about negative 0 and pursue the question in further conversations and debates.[3]

The mathematics discussed in Ms. Keith's class is not finite or fixed nor are the mathematical ideas typical of the first grade. Some would say they are unusual, if not exceptional. Ms. Keith herself acknowledges that the mathematical ideas that her first-graders are considering are different from those she used to teach and from those in a typical scope and sequence chart for first grade. These new ideas include odd and even numbers, negative numbers, and infinity. She says that in a traditional first grade class, "numbering starts at 0." But Annie Keith herself remembers being confused as a child when she was taught later that there were "other numbers besides 0 because for so long she was just taught that numbers start with 1 and go on, and then you have this 0 appearing, and now there's something else!" In contrast, in her class she said that from the first day of the first week of school, her students were talking about infinity and about the idea that numbers go "either way" or in "both directions." They were talking about these mathematical ideas because the children brought them up and because they were interested in them and puzzled by them.

Annie recounted a story of how negative numbers continued to be a focus of conversation in the classroom. One day T. J. came up to Annie, having written in his mathematics notebook this problem: "There were 12 dogs and 25 of them ran away. How many dogs are there?" T. J.'s answer was negative 13 dogs. Annie continued her recounting of the story:

> Greg Thoyre, a graduate student with the CGI project, came up to T. J. and said, "You know, T. J., I'm having a really hard time visualizing this problem. You know if there are this many dogs, and this many run away, I don't know. What would negative 13 dogs look like?" T. J.

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[3] *In reading an earlier draft of this chapter, noted psychometrician and educational psychology professor Lee J. Cronbach was intrigued by this discussion of these six-year-olds' discussion of the possibility of the existence of negative 0. Cronbach recalled an instance in which he actually got "-0" on a computer printout due to the procedure that the computer used to round numbers. Another university professor, Susan Luks, read this episode and recalled a recent instance in which her adult computer science students had vigorously debated the existence of negative 0 as they were learning to program in the computer language "C." In computer language one of the "bits" indicates whether the number is positive or negative. Luks's adult students puzzled about how then to represent 0 in computer language. They proposed the idea of "negative 0" and "positive 0" to try to solve their problem.*

goes. "Oh, there wouldn't be any 'cuz below 0, you wouldn't see any. You just have to 'magine. It would be negative 13."

Annie and T. J. continued to talk, and they came up with a mathematical representation that helped them think about negative numbers — using thermometers. They talked about using things where they could "see" negative numbers and how they could write story problems that would reflect things in the environment around them.

Annie's story portrays how mathematics and worthwhile mathematical tasks are created in her first grade class. They come from the children, and the mathematical knowledge, representations, problems, and tasks the children create are very much theirs as well as hers.

In an interview in May 1990 Annie noted that throughout her own schooling she had hated mathematics, and she had been "math phobic." In her pre-service teacher education at the University of Wisconsin-Madison, Annie took two courses in mathematics for elementary school teachers. When she began teaching seven years ago, she still did not feel comfortable with mathematics. The turning point was when she became involved in the original CGI project after her first year of teaching. Annie now credits her first grade students for their positive influences on her mathematics understanding and her confidence and interest in learning mathematics. She says that she has learned "how much fun math really is, and how exciting it is." She says that she learned the "whole idea of place value with understanding through watching these kids."

6.12 Learner's Knowledge

In discussing the six- and seven-year-old students in her class, Annie says that "her kids know so much." By this she means not only that her children know much of the domain of elementary school mathematical knowledge as she construes it, but also that the children have knowledge, understanding, and insight that she does not have. From their perspectives as children in a multicultural school in a diverse society in an information age, the children bring to the classroom, and create within it, important understandings about mathematics, learning and teaching, relationships, and living and working together. Because Annie believes that children have a lot of knowledge, she believes that she learns much from them, and, indeed, she credits much of her change to learning from her students.

Ms. Keith makes visible through her words and actions that she learns from her children. Because learning includes all parties — teachers and students — Ms. Keith is not the only authority for knowledge in the classroom. Their are multiple authorities and multiple ways of knowing. In her classes, students "prove" their mathematical solutions to themselves and to others, explain why they think something is true, and give reasons and justify their thinking. Even Ms. Keith has to justify her reasons and her actions to her students. She says that some teachers might consider CGI students a little "obnoxious" because they expect their teacher to listen to them and take them seriously. She talks about how her students are already empowered in first grade because they had CGI in kindergarten. The students expect to be able to share all their ways of solving mathematical problems, and if she stops discussion before they have been heard, the students want to know why.

Annie creates a learning environment where students bring up mathematical ideas, choose and create problems and mathematical tasks that interest and challenge them, and justify their mathematical thinking to themselves and their community. Authority for knowing and learning rests with the students and the community rather than only with the teacher. Such a learning environment seems designed to foster mathematical power in the ways suggested by the *NCTM Standards*.

6.13 Learning in a Community: Learning as a Social as Well as an Individual Act

The learning context in Ms. Keith's classroom is one of community; Annie Keith attempts to help her students see themselves as a community of mathematicians. At the beginning of the year, the class jointly defined the following qualities of mathematicians:

> Mathematicians listen to each other. Mathematicians never say "can't." They will always do their best and try their hardest. Mathematicians help each other. Mathematicians can solve a problem in many ways. Mathematicians use different kinds of math tools.[4]

When in her classroom, Ms. Keith is often heard to repeat aloud these ideas about mathematicians. These words serve to make explicit not only assumptions about how mathematical knowledge is created, but also the norms for discourse and learning in the classroom.

In Ms. Keith's classroom, as in a community of real mathematicians, worthwhile mathematics problems and tasks are constructed jointly by the participants. In the whole-class meeting each day, mathematics emerges as part of the flow of the ongoing conversation. In her mathematics learning centers. Ms. Keith herself still often decides what the mathematics tasks will be. Increasingly she has moved toward having the students themselves plan what will happen in the mathematics learning centers for the week. On an ongoing basis, her students decide what problems are challenging and interesting for them. They think about mathematics and converse about and wrestle with mathematical ideas. In the process they are involved in inventing a new mathematics curriculum insofar as they are expanding previously conceived notions of what kinds of mathematical ideas first grade students are interested in and capable of thinking hard about.

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[4] *These qualities were not derived from any direct knowledge of specific or actual communities of mathematicians. Rather, they represent Ms. Keith's and her students' ideal of how they want to function as a community investigating mathematical ideas.*

6.14 Conversing: Listening, Querying, Justifying, and Making Thinking Visible

Listening is an important part of mathematics learning and teaching in Ms. Keith's classroom. Listening serves the same purpose that it does in ordinary conversation — for the participants to come to understand the others' perspectives.

In Ms. Keith's class, students talk and listen to one another rather than solely to the teacher. The students and the teacher take students' responses seriously and treat them with respect. Why? Ms. Keith provided one rationale when she told me about how they talk about listening in her classroom:

> I always go through this thing where I say to them, "Yeah, but I'd done first grade. I don't even have to listen to you guys anymore." They just get appalled; they think that's just horrendous to say that. And they'll give me all the reasons why I need to listen to them. They know so much, and they'll say, "You really need to listen to us today so you know what we're doing and how we're solving the problems. You need to listen to us because you can learn some new things from us. You need to listen to us because you have to fill out report cards and tell our parents what we're doing. You have to listen to us so you know if we've learned new things. You have to listen to us so you know what kind of problems to give to us."

Questioning is encouraged. The teacher asks many questions as well, but they are a different sort of question than is asked in most classrooms. The form of Annie's queries in this episode are most frequently "Why?" or "What are you thinking?" These questions elicit from the students their descriptions of their thinking and their justifications for their ideas, and answers. Such questions also focus discussion around the ebb and flow of students' thinking, and indeed the words "think" and "thinking" are used more than forty times by Ms. Keith or the students during the hour-long class conversation on negative numbers and 0. As in most mathematics classrooms, the teacher questions the students. But unlike most classrooms, the students also query one another and their teacher.

Also in contrast to most other classrooms, Ms. Keith's responses to students' ideas is nonevaluative. She withholds judgment, often saying, "Hmmm," in response to students' comments. In the videotape of the session, Ms. Keith's nonverbal behavior expresses sincere listening. The only time that Annie "told" the students something during this episode was when she said that positive numbers and "regular" numbers were the same (and this idea was actually introduced by Peter, not Ms. Keith). Her stance is related to her desire to transfer the authority for knowing to the community of mathematicians in her classroom.

6.15 Conclusions and Implications for In-service Programs

Just as Annie Keith's teaching brings forth new questions from her students, so does her teaching raise new questions for teacher educators, reformers, mathematicians, scientists, and researchers. Several questions are of greatest concern:

- Is Annie Keith sacrificing functional mathematical literacy in order to achieve meaningful communication?

Research to date suggests that in teaching mathematics in this way, teachers like Annie Keith are not sacrificing mathematical literacy for the sake of communication. Rather their students learn basic facts and mathematical concepts to the same degree as students in traditional classes, but they do so within the context of solving mathematical problems and through thoughtful discussion and engagement with mathematical ideas. They also have greater flexibility in the ways they are able to solve problems (Carpenter, et al., 1989; Peterson, et al., 1991; Resnick, Bill, Lesgold, & Leer, 1991; Wood, Cobb, & Yackel, 1992). But researchers have only begun to explore what this kind of teaching means for students' learning of mathematics. Scholars in the next decade will undoubtedly become more sophisticated in their understanding of variations of this kind in mathematics teaching, as more and more teachers attempt to implement the *NCTM Standards* in their classrooms. As educators assess what mathematics students are able to learn in these new situations, they also will be in a better position to address the question of whether or not students are gaining in mathematical literacy as well as in mathematical power and their abilities to solve problems, communicate, and think mathematically.

- Does the kind of mathematics teaching that Ms. Keith is doing require "more" mathematical knowledge than the typical experienced teacher now has?

Mathematician and cognitive scientist Alan Schoenfeld addressed this question as he mulled over the case of Annie Keith and confronted his own thinking about reform:

> When Annie Keith teaches in this new way, she has a lot more flexibility, and her students explore a lot of interesting mathematics. The example of a student rediscovering Pythagorean notions was a nice case in point. But it's not true that there's no "can't" in mathematics, at least not literally — once definitions are made, some things can be done, and some can't. In moving from teacher as dispenser of (a very narrow slice of) truth to teacher as facilitator of sense-making, Annie Keith and others take on a much greater burden than before. They have to negotiate between the students' current understandings and (a paraphrase of Kitcher) "what the mathematics allows them to do." To be done well, this calls for "more" mathematical knowledge, for the teacher is exploring with the students. The fear of some of my colleagues is that without such knowledge, and a sure guiding hand, we might have a rerun of the (caricature of) discovery learning — the kids have a good time, but what do they learn, and when do they learn to sort out mathematical right from wrong? (Alan Schoenfeld, personal communication, Sept. 28, 1992).

If this kind of mathematics teaching requires "more" mathematical knowledge than the typical teacher now has, then where are experienced teachers going to get this knowledge? Will teachers be able to get along, as Annie Keith does, by learning mathematics along with her students, and then enrolling in an additional mathematics course when she sees the need? Can teachers get the kind of mathematical knowledge they need by taking a course in mathematics at a local university? Or do teachers like Ms. Keith need a kind of mathematical knowing and understanding that differs from what teachers have typically "received" from professors in their mathematics classes during pre-service education? Do they need to experience the learning of mathematics in the same ways as their students do? And do they perhaps need to take more courses in the history and philosophy of mathematics so that they understand and recognize as important those mathematical ideas that their children bring up, ideas that mathematicians have also wrestled with and written about?

During this year of teaching, Annie Keith has been exploring the question of what would happen if she "told" students much less than she had previously told them about mathematics. Her stance is one that many assume as they first experience a change in their thinking away from a transmittalist view of instruction. But clearly students do learn from "telling," and students cannot be expected to reconstruct the entire field of mathematics, can they? A critical question thus becomes

- What role can "telling" by more knowledgeable, as well as less knowledgeable, others play in learning mathematics?

These are all questions that deserve further thinking. These are also questions that investigators might address as part of research and evaluation conducted within ongoing in-service programs in mathematical sciences education.

The way that Annie Keith teaches first grade mathematics, and the assumptions she holds about mathematics learning and teaching are remarkably different from those she held six years ago. Similarly, over the last decade scholars have revised considerably their assumptions about mathematics learning, from a behaviorist view of learning toward more constructivist views. Interestingly, unlike most experienced teachers, Annie Keith has revised her assumptions about mathematics learning and teaching in ways that are remarkably like those of the scholarly community. Why might this be the case? A seemingly simple answer to this question is that Ms. Keith is a learner and she sees herself as one. But this answer is more complex and multifaceted than it first appears.

One facet of Annie Keith as a learner concerns her perspective on knowledge. For Annie knowledge is dynamic, fluid, changing, and growing — not fixed, static, or inert. This is the way she sees her own knowledge — she is learning from everyone around her. But it is also the way she sees her first-graders' knowledge and the knowledge of her teacher colleagues. Ms. Keith is engaged in her own exploration and analysis to figure out how her first-graders construct knowledge while participating in a learning community where they talk about, debate, and create mathematics problems. With this exploration, she is venturing into new domains of mathematical knowledge for first-graders, as well as herself.

Another way of conceptualizing Annie Keith as a learner is that she participates as an active member of multiple learning communities or multiple communities of discourse. She has been a teacher for six years. In this role, she participates as a member of the professional communities and associations in reading and mathematics to which elementary school teachers often belong. She reads the journals and magazines that elementary school teachers read. But she has also created a smaller discourse community — a community of teacher-learners at Muir School. And within that community there is an even smaller community, defined by the first grade teachers on Annie's team. A second major discourse community within which Annie now participates is the community of researchers and university professors. On her days off Annie feels free to go to the CGI offices at the university and spend the afternoon talking about her teaching with CGI project leaders Elizabeth Fennema, Tom Carpenter, and Megan Loef Franke, as well as the graduate students there. By doing so, she has access to the online thinking, knowledge, and understanding of leading-edge scholars. Most teachers would not have such access except through reading research articles or attending a national conference. Through these conversations with Annie Keith the researchers also have online access, to the knowledge, thinking, and understanding of a first grade teacher fresh from the challenges of learning and teaching a new mathematics in new ways to a diverse group of wriggling, laughing, boisterous young learners.

A third important facet of Annie Keith as a learner is that she is considered to be a knowledgeable participant by the members of the multiple learning communities in which she participates. These include her teacher colleagues at Muir school on her primary team, who respect her knowledge and thinking and with whom she engages in joint planning and sharing of ideas for mathematics teaching. It also includes the CGI researchers and teacher educators with whom she works. Carpenter, Fennema, and Loef Franke assert explicitly that they assume that teachers are knowledgeable learners, just as they would like teachers to assume that their students are knowledgeable learners.

A fourth facet concerns the patterns of discourse and negotiation of meaning that seem to be occurring in Annie Keith's mathematics teaching, reflected in the class conversation about negative 0. These discourse patterns and ways of negotiating meaning seem to be reflections of experiences that Keith herself has had this past year — she has interacted with a graduate student, Ellen Ansell, who has been doing a case study of students' mathematics learning in Keith's classroom. Both Ansell and Keith report on the power of this kind of reflective dialogue for learning, and their reports are remarkably similar to those of other researchers who have engaged in such dialogues with practitioners (Schon, 1983; Berkey, Curtis, Minnick, Zietlow, Campbell, & Kirschner, 1989).

Ellen Ansell said she frequently asks Annie questions about what she does and why. These kinds of questions and conversations occur around nearly every mathematics class that Ellen observes. They occur at least once a week, and often more frequently. If Ellen sees something interesting during math class, she asks Annie about it and asks if it surprised her.

Annie says that Ellen helps her to see things by pointing out "inconsistencies" in what she is seeing or saying about what a child has done or said in mathematics. These conversations lead Annie back through the work that the child did earlier that showed something unusual. In turn Ellen has noticed that one way that Annie works with her children is with questioning to lead them to see inconsistencies in their own reasoning or solutions, or in what they have said or done both individually and as a group. This kind of questioning tends to then get further reflected in the way the children talk with each other. Ellen has noted that Annie's students will use this same way of questioning or thinking when they are on their own or with other children.

One conclusion, then, to be drawn from this case is that if teacher educators want teachers to act on revised assumptions about students' mathematics learning, then teacher educators must apply these same assumptions to teachers as learners. Annie Keith's experiences as a learner were reflected in her own assumptions about her students' learning and then enacted in her mathematics teaching. And although this is only one case, substantial evidence exists for the need for educators to work from the same shared assumptions about learning, and to apply these same assumptions in their teaching at all levels. Cooney (this volume) discusses research and theory to support this position in the case of teacher education.

From the perspective of the larger educational system and the need for systemic change, Cohen and Barnes (1993) have argued that the same model of learning should be applied at all levels of the educational system. Thus the learning assumptions described above might be used to frame the work not only of teachers and learners in their classrooms, but also of teacher educators, teachers as learners, and the work of policy makers and researchers as learners. The to-be-hoped-for outcome would be an educational system that is truly a learning system in which participants at all levels are engaged in their own learning and development of understanding as well as in the creation of new educational knowledge. Such a system would be one which would encourage more teachers to be learners like Annie Keith, but would also encourage more first graders like Erica and my daughter, Elissa, to query their teachers and their classmates about infinity, and negative numbers, and to consider the possibility that negative 0 could exist after all.

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7 QUESTIONS ABOUT THE MATHEMATICS CURRICULA FOR GRADES K-12

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7.1 Introduction

Deliberate teaching requires choices as to what to teach (Kliebard, 1977).

Mathematics teachers in schools today are faced with a conflict between the reality of a traditional curriculum and calls for radical change in what they teach. This chapter provides background information for those investigators, consultants, and scholars committed to helping schools, via teacher enhancement programs, to help teachers and school staffs to understand this conflict. Teachers need to consider and answer for themselves a number of questions about the mathematics curriculum as they attempt to address the conflict. Only by reflection and communal discourse will they understand the issues and become active participants in the reform movement.

The term "curriculum" refers to a course of study, its contents, and its organization. The calls for change imply that the mathematical content that society would like students to have an opportunity to learn in the schools has changed. Simply listing, however, new content, or changes in current content, or even describing the "increases" or "decreases" in emphasis in content domains — while necessary — would never be sufficient. This is because of, as Goodson calls it, "the trilogy of pedagogy, curriculum, and examinations" (1988, p. 32). In practice one cannot divorce content from how it is to be taught and assessed. Thus any strategy for change must consider what is to be taught, how it is to be taught, and how the performance of students is to be judged. Nevertheless, for this chapter, the focus is on the mathematical content students should have an opportunity to learn and how it should be organized.

The following five questions are used to shape the way the conflict between current practice and change may be considered by teachers:

1. Why change the content and organization of the mathematics curriculum?
2. What are the salient features of the current mathematics curriculum?
3. What content and organization are being advocated?

4. How is the mathematical sciences education community planning to implement these changes?

5. What are some of the issues and problems reformers will face?

7.2 Why Change the Content and Organization of the Mathematics Curriculum?

The simple answer to this question is that the current system is not working well for most students and for the nation. Teacher enhancement programs must challenge participants with the evidence from a variety of sources about the limitations of current practices, and they must directly confront long-established traditions in the mathematical content and the organization of the curriculum.

As a society we have accepted the possibility that many students will never learn to do any mathematics beyond shopkeeper arithmetic. The evidence that all students need to learn more and somewhat different mathematics in schools has been summarized by the Mathematical Sciences Education Board (MSEB) in *Everybody Counts* (1989), and *Reshaping School Mathematics* (1990a). Teachers and staff members need to discuss this evidence and determine for themselves its impact on what mathematics is taught.

7.2.1 Student Performance

The first evidence usually cited to indicate that our mathematics education system is in trouble is the bleak national performance data. For example, results from the National Assessment of Educational Progress (NAEP) in mathematics (Lindquist, 1989) show that although most students are reasonably proficient in computational skills, the majority do not understand many basic concepts and are unable to apply the skills they have learned in even simple problem-solving situations. Also, our students do not fare well when compared with students in other industrialized nations (McKnight, Crosswhite, Dossey, Kifer, Swafford, Travers, and Cooney, 1987). We expect less of our students, they spend less time studying mathematics, and fewer of them are enrolled in advanced mathematics courses than is the case in other countries (Travers and Westbury, 1989).

The performance and enrollment picture is even bleaker for women and most minorities. If our inequitable schooling practices are allowed to continue, this condition will become worse. Affluent, suburban school districts already provide their students more opportunities and resources for the study of mathematics than do most urban districts, and are often likely to be the first to react substantively to crises in education and recommendations for change. They are already spending more money than urban districts on computers and teacher in-service education, thus further widening the opportunity gap between affluent, suburban students and their poor, urban counterparts.

By any criterion, typical American students do not perform well. But test score evidence by itself may lead to inappropriate conclusions. Current poor test performance does not necessarily indicate that there has been a decline in performance. In fact, American students have never scored well in NAEP tests (e.g., Carpenter, Reys, and Wilson, 1978), nor have they compared favorably with students in most other countries (e.g., Husen, 1967). In fact, Beckmann (1970) presented evidence that a group of American students in 1965, while not scoring very highly, were more mathematically literate than a similar group in 1950. Thus it is false to argue that educators should return to the practices of a romanticized past. Earlier in the century we were able to ignore overall poor performance because enough students were continuing to study mathematics to meet our economic needs, or we were able to recruit mathematically trained people from other countries. On the basis of prevailing assumptions, we excused ourselves by claiming that most students only needed to know how to perform arithmetic operations and that it was all right not to do well in mathematics, particularly for women and minorities. And, if one did well, it was because of ability, not opportunity, effort, or interest. Today we know these assumptions are false.

While this evidence about student performance does not indicate what content should be taught or how it should be organized, it is clear that a serious problem exists. It also suggests we should not retreat to romanticized past practices or use excuses to resist change.

7.2.2 Needs of Business and Industry

A second argument for change comes from business and industry. The conclusions in *A Nation at Risk* (National Commission on Excellence in Education, 1983) and *Educating Americans for the Twenty-First Century* (National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, 1983) were that schools are failing to educate students to be productive employees for today's workplace. Schools, as presently constituted, are the products of an industrial era that has ended. The school mathematics curriculum still reflects the industrial needs of the 1920s, not the workplace needs of the 1990s. The Mathematical Sciences Education Board (1989, 1990a) argues that to be economically competitive in the 21st Century, all students will need to know somewhat different mathematics than is currently covered in the programs of most American schools.

Several authors (Naisbitt, 1982; Shane and Tabler, 1981; Toffler, 1985; Yevennes, 1985) have described some of the attributes of the "information age." It is based on a new technology that replaces the traditional human and mechanical means of communication -- the printed page, letters — with electronic means by which information can be shared almost instantly anywhere. Information is the new capital and the new raw material. Communication is the new means of production. The impact of technology is an economic reality, not merely an intellectual abstraction. As a result, the pace of change will be accelerated by continued innovation in communications and computer technology. Also, while the new technologies were originally applied to old industrial tasks, they are now generating new processes and products. Finally, basic communication skills are more important than ever before, necessitating a literate society.

This shift has immediate consequences for schooling and, in particular, for the teaching and learning of mathematics. The content and structure of the curriculum should not operate on the basis of past values but should be derived from visions of the future (Shane and Tabler, 1981). All students should be taught to reason, design models, and solve problems. The most important attribute of the information economy is that it represents a switch from physical energy to brain power as the driving force, and from concrete products to abstractions as the primary outcomes. Instead of preparing all but a few of our youth to function smoothly in a largely industrial system, all children must be taught critical-thinking skills. While creative intelligence is the driving force, innovation and appropriate uses of innovation depend on communal intellectual effort rather than on the activity of a small cadre of elite thinkers.

This evidence of the shift to the "information age puts the emphasis for change on future needs and indicates a necessary direction for change, but again it fails to specify what content should be taught.

7.2.3 Democratic Citizenship

The third argument for change evaluates the need for all citizens in a democracy to become "mathematically literate." Ote Skovsmose refers to this as "the problem of democracy in a highly technological society" (1990, p. 109). The conviction that democracy will prevail cannot be taken for granted in this highly technological information age, to the extent that democracy requires competence in the society. Arthur Jaffe makes the following claim:

> In the past quarter century, mathematics and mathematical techniques have become an integral, pervasive, and essential component of science, technology, and business. In our technically-oriented society, "innumeracy" has replaced illiteracy as our principal educational gap. . . . In fact, we could say that we live in an age of *mathematics* — the culture has been *"mathematized"* (1984, p. 117)

Christine Keitel points out that the process of *mathematization* involves specialists and experts "outside ordinary democratic control and outside the competent 'discourse' in society" (1991, p. 11). The danger is that democracy could be replaced by an "expertocracy." She goes on to argue:

> How is it possible to combine democracy with the necessity of selecting a small group of experts to actually advise or do the ruling? How is it possible to control the "people in charge"? While the ruling-competence of the people in charge is of special nature, the judging-competence is of common nature: we could call it democratic competence. In other words, democratic competence should be a common capacity of human beings and has to be produced by education. Democratic competence does not only mean a certain system of knowledge or abilities, but a certain attitude: To be willing to stress the importance of a democratic way of social control and acting. (p. 11)

Thus democratic competence in a highly technological society includes both technical knowledge of mathematics and its uses and the reflective knowledge necessary to analyze and evaluate technological developments. To meet this challenge of preparing all students to be democratically competent, Philip Davis (1990) has called for changing mathematics education from teaching the "grammar" of mathematics to teaching its "literature," e.g., focusing on alternative modeling activities, which should lead to critically analyzing and judging the applications of mathematics. The point is that discussing and criticizing a mathematical model does not depend simply on technical knowledge about the modeling process. It must also be based on reflective knowledge about the criteria used in the constructions, applications, and evaluations of mathematical models for social problems.

This evidence implies that instruction for all students needs to be based on the modeling of applied problems rather than on mastering procedural skills. The key feature of the evidence pertaining to both business and industry and democratic citizenship involves getting students to use technology to do routine manipulations (which is a large part of what is currently emphasized in mathematics classes) and concentrate instead on learning to conjecture, construct models, and build arguments. This feature is based in part on the fact that, in the past quarter century significant changes have occurred in the nature of mathematics and how it is used. Not only has much new mathematics been discovered, but the types and variety of problems to which mathematics is applied have grown at an unprecedented rate. One of the most visible aspects of this phenomenon, of course, has been the development of computers and the explosive growth of computer applications. Most of these computer applications have required the development of new mathematics in areas where applications of mathematics were not feasible prior to the advent of computers (Howson and Kahane, 1986). Less visible. t equally important, has been the enormous wealth of ideas generated in several main branches of mathematics that are linked by unifying concepts of widespread applicability (e.g., Board on Mathematical Sciences, 1986). Students must study the mathematics used in such applications in order to grasp its power to solve real-world problems and reflect on the consequences of such uses.

To illustrate — because the computer can carry out prodigious calculation feats, its impact on mathematics is similar to the impact of the printing press on writing and reading. The printing press, which made certain skills (calligraphy) obsolete, also made texts increasingly available, vastly increasing the need for people to write and read. Similarly, today's computer technology has rendered a certain range of skills (complex paper-and-pencil calculations) obsolete, thus making it more widely possible for people to model complex problem situations, make predictions, and so on. Television, satellites, robots, complex financial service, and high-tech corporations — all would be impossible without this changed perspective about mathematics.

7.2.4 Theories of Learning

Another source of evidence for change comes from research on learning. This evidence has little to say about what mathematical content students should have an opportunity to learn but much about how it should be organized and taught. There has been a shift in mainstream American psychology from its associationist and behaviorist traditions to the study of cognition. This shift provides evidence on how knowledge is acquired (Calfee, 1981; Greeno, 1987; Mestre, this volume; Pea, 1987; Peterson, this volume; Putnam, Lampert, & Peterson, 1989; Resnick, 1987). Virtually all cognitive theorists share the fundamental assumption that an individual's knowledge structures and mental representations of the world play a central role in his or her capacity to perceive, comprehend, and act. An individual's perception of the environment and his or her actions are mediated through cognitive structures that are actively constructed and modified as a result of experience. This mediation through cognitive structures provides a basic definition of knowledge in cognitive theories. Knowledge is composed of the cognitive structures of the individual. To know and understand mathematics, from this perspective, means to have acquired or constructed appropriate knowledge structures.

Since an individual student constructs his or her knowledge in a social context, and this context helps to shape the constructed understanding, the organization of the curriculum must reflect this perception. Instructional activities should build on what students already know and encourage interactions between students as they try to understand the mathematics being studied. The *Professional Standards for Teaching Mathematics* refer to the classroom as a "mathematical community" (NCTM, 1991, p. 3). A key feature of the environment of a classroom is its discourse: "The discourse of a classroom — the ways of representing, thinking, talking, agreeing, and disagreeing — is central to what students learn about mathematics as a domain of human inquiry with characteristic ways of knowing" (NCTM, 1991, p. 34).

Hiebert presents three reasons why communication is an important part of the mathematics classroom. First, communication is an integral part of what it means to do mathematics, in that "doing mathematics means agreeing on assumptions, making assertions about relationships, and checking if the assertions are reasonable" (1992, p. 444). Second, by working collaboratively students can construct knowledge and understandings that they would not develop working alone. Third, communication as social interaction allows for the possibility of developing shared meanings, so that the mathematics of one student fits with the mathematics of others.

This psychological data suggests that curriculum units need to be based on problem situations organized around essential issues that get at fundamental concepts, problems, or principles of mathematics. To do that, a unit should have an ongoing "story-shell" that relates specific activities to a larger, coherent "story." Only by carrying out such activities in such a context will students construct meanings for mathematical symbols.

7.2.5 Equity in a Changing Society

Still another argument for changing the way mathematics is organized and taught is that fact that mathematics has been "a white male domain." *In Everybody Counts*, the Mathematical Sciences Education Board (1989) describes the changes in demographic trends with respect to students and the workforce in this country. In the long run the most important factor affecting education is the changing profile of students.

- By the year 2000, one in every three American students will be a member of a minority group; by 2020, today's minorities will become the majority of students in the United States.
- Sixty percent of children born in the 1980s will, before reaching the age of 18, live in a home with only one parent.
- More than one child in four comes from a family that lives in poverty; nearly one in five comes from a home in which English is not spoken; and one in three comes home to an empty house, with no adult to greet the child and encourage attention to homework.
- The children of today's high school dropouts are the high school students of the first decade of the twenty-first century.
- Between now and the beginning of the twenty-first century, one in three new workers will be a minority group member.

Changing demographics have raised the stakes for all Americans. Never before have we been forced to provide true equality of opportunity to learn. The challenge we face today is to achieve what we believe, or what we say we believe.

Again, while this evidence for change has little to say about what should be taught, it adds to our understanding of the seriousness of the problem. It also suggests that we must begin with the assumption that all students can learn mathematics and that all deserve our best efforts in helping them learn.

7.2.6 School Mathematics in Other Countries

The final source of evidence for change comes from an examination of what mathematics other countries include in their school curricula and how they are organized. For too long most Americans have been provincial in their thinking about schooling in other countries. As contact with educators from other nations has increased, two things have become evident. First, the way we have organized mathematics courses for most students (eight years of arithmetic, a year of algebra, a year of Euclidean geometry, another year of algebra, and so forth) is not the way courses have been organized in other nations. Maths (not math) has been emphasized in an integrated manner throughout the curriculum in many countries. Second, the current reform movement in school mathematics is international and began more than a decade ago in many other countries.

This evidence for change, while not compelling on its own because of the many cultural differences in the way schools are organized in different countries, has become salient because of economic competitiveness. In particular, when this evidence is coupled with the needs of business and industry and the inadequate performance of American students in mathematics, it suggests we may have something to learn from other nations. For example, we need to understand how Japan and most European countries organize and teach mathematics so that all students have an opportunity to learn algebra, geometry, and even the beginning notions of calculus.

In summary, the evidence is overwhelming that our students and the needs of our democratic society are not being well served by the current school mathematics program. Teachers and school staffs need to consider and discuss this evidence, determine the degree to which the problems are reflected in their school and community, and initiate plans for reform.

7.3 What Are the Salient Features of the Current Mathematics Curriculum?

To change both the mathematics now contained in the curriculum and the way it is organized, teachers should come to understand the important features of the system as it now operates. In the first part of this section, titled "Conformity Within Diversity," I attempt to describe the complexity of the public school systems of the U.S. and how those systems have evolved. With the first part as a backdrop, the next three parts describe "what it means to know mathematics," the "job of teaching," and the "activities of students" in typical American schools. Although the picture that is presented is admittedly a stereotype, it is real in too many schools. Then, in the final part, titled "The Industrial Model," I describe the limitations of the current schooling organization.

7.3.1 Conformity Within Diversity

When foreign educators first visit the U.S., one of the features most striking to them is the diversity of schooling practices here. This is particularly so with respect to governance and how policy decisions are made. The Constitution of the United States, by omitting any reference to education, left decisions about education and educational policy to the states. The states in turn have, to varying degrees, turned over the control of schools to local communities with locally elected school boards. These school district boards hire administrators and teachers and approve programs. There are over 15,000 school districts in the U.S., containing more than 50,000 elementary schools, 9,000 junior high schools, and 13,000 senior high schools. As a consequence of shared state and local control and shared state and local taxes to support schools, there are vast differences in the quality of programs, facilities, staff, and teachers, both across and within states.

There is no national curriculum, no national set of standards for the licensing or retention of teachers, no common policies for student assessment of progress or admission to higher education. One primary reason for this educational diversity is that

> American schools, like public schools in other industrialized countries, are the inheritors of two quite distinct educational traditions — one aimed at the education of an elite, the other concerned with mass education. These traditions conceived of schooling in different terms, had different clienteles, and held different goals for their students. Only in the past 60 years have the two traditions merged (Resnick, 1987, p. 5).

These two types of schools have been labeled "high literacy" and "low literacy" (Resnick and Resnick, 1977). The "high literacy" schools were, and still are, for the elite. They are private, or religious, or special academic facilities in states or large cities, or situated in affluent communities. Only a minority of young people are admitted to and attend such schools. The curriculum in such schools is strictly academic, aiming toward university entrance at the "best" universities in the country.

Schools for the "masses" arose from different roots and were aimed at producing minimal levels of competence in the general population. When the U.S. was founded, village schools were established reflecting the notions about a literate citizenship appropriate to the new nation. The educational system that then evolved during the nineteenth century focused largely on elementary schooling. This produced a sharp distinction between elementary and secondary education that still persists. Almost everyone went to school for up to eight years, but few went on to high school. The "low literacy" curriculum focused on the basic skills of reading, writing, and computation. Teachers in elementary schools were expected to teach all students all of the curriculum, while secondary teachers were subject-matter specialists. The political conditions under which mass education developed encouraged the routinization of basic skills, standardized teaching, and other such phenomena. Standardization was a means of insuring that at least minimal curriculum standards would be met, teachers would be hired on the basis of competency for the job rather than political or familial affiliation, and those responsible for the expenditure of public funds could exercise orderly oversight over the process of education. This standardization was also a consequence of the notions about the efficiency and effectiveness of routinization which grew out of the industrial revolution of the nineteenth century (Bobbitt, 1924; Charters, 1923; Rice, 1913).

It has only been since the Second World War that the institutional division between routine-oriented elementary schools and secondary academies has been dissolving. Responding to changing economic and social conditions, more and more young people started to seek high school educations. The consequence has been to develop "comprehensive" high schools, which are common today.

In summary, the most common pattern of schooling until the 1950s was for all students to be required to attend an elementary school for eight years (ages 6-14). Each school housed some 200 students grouped by age (Grades 1-8) and further grouped into classes of 20-30. These classes were taught all subjects for the school year by the same teacher. Even though there have been changes, in 1975 the National Advisory Committee on Mathematical Education (NACOME) commissioned a study of elementary school mathematics instruction. The picture drawn from that survey is as follows:

> The "median" classroom is self-contained. The mathematics period is about 43 minutes long, and about half of this time is written work. A single text is used in whole-class instruction. The text is followed fairly closely, but students are likely to read at most one or two pages out of five pages of textual materials other than problems. It seems likely that the text, at least as far as the students are concerned, is primarily a source of problem lists. Teachers are essentially teaching the same way they were taught in school. Almost none of the concepts, methods, or big ideas of modern mathematics programs have appeared in this median classroom (Conference Board of the Mathematical Sciences, 1975, p. 77).

School lasted some six to seven hours a day, five days a week, for nine months (September to June), with two weeks' vacation at Christmas and a week off at Easter. The long summer vacation was deemed necessary so that both students and teachers could help on the farms.

Secondary schools followed the same basic schedule except that they housed some 1,000 to 2,000 students for four years (Grades 9-12). Attendance was not mandatory. Thus, many students never went to high school, and many who started did not graduate. Classes were organized around subject disciplines (English, science, social studies, mathematics, etc.). Each class met five days a week for a semester (half a year) or for the year. Each class was taught by a teacher who had been trained to teach that subject. Thus a student would take five or six different classes a day from different teachers.

During the past 60 years there have been many changes in the common pattern of schooling in the U.S., of which three deserve mention. First, kindergartens have been almost universally added to the elementary schools. These comprise a half day of schooling for five-year-olds to acquaint them with the routines of schools so that they become familiar with the distinctions between work and play, etc. (King, 1981). Second, compulsory schooling has been extended from age 14 to 16 (18 in some states). This has changed the clientele of secondary schools from just those preparing to go to college to all persons of those ages. In turn this has changed the course offerings from strictly academic subjects to a vast melange. In fact, while schools have continued to require academic courses for high school graduation, the requirements have become minimal and the course content modified and made less demanding. Third, to accommodate the problems of emerging adolescence and the transition to high school for the masses, a new school (called junior high or middle school) has become common. These schools are for 400 to 600 students for three years (Grades 6-8 or 7-9) and have features of both elementary and secondary schools.

Another feature of American schools which strikes foreign scholars as strange is the emphasis on athletics, drama, marching bands, and other forms of entertainment in our secondary schools. This emphasis grew with the development of schools in the then-isolated villages and small towns of the Midwest in the century prior to the Second World War. Schools in these communities were, and often still are, the focus of the social life of the communities. Football games, school plays, or musical programs are attended by the entire community. Thus, schools in the U.S. have a broader social function within local communities than just to educate the young.

What I have attempted to portray in this part is the fact that the schools in America are diverse. The reasons for this diversity are historic, economic, and political. Nevertheless, what has evolved in the latter half of this century is a comprehensive schooling pattern that characterizes the majority of schools in America. It is this common pattern with respect to mathematics instruction that is described in the next three parts.

7.3.2 What Does It Mean to Know Mathematics?

For most Americans mathematics is a very large collection of concepts and skills that are hierarchically arranged in a strict, partial order (Romberg, 1983). John Dewey's (1916) distinction between "knowledge" and the "record of knowledge" may clarify this point. For most Americans, to know mathematics is to identify its artifacts (its record). Few are able to create or use mathematics. Thus, the epistemological basis for mathematics instruction begins with this static and bounded notion of the discipline. The acquisition of information and being able to demonstrate proficiency at a few skills has become an end in itself, and students spend their time absorbing what others have done.

The goal for students is to sequentially master one concept or skill after another. Furthermore, the student's task is to get correct answers to well-defined problems or exercises. This method of segmenting and sequencing in school mathematics has led to an assumption that there is a strict partial ordering to the discipline. Thus, in American schools, you cannot study geometry unless you can solve linear equations or do algebra unless you have mastered arithmetic.

The usual way of describing what mathematics is taught to students in American schools is to describe the topics that are covered at various grades. The emphasis in the elementary schools is on arithmetic computational proficiency. The standard topics include addition, subtraction, multiplication, and division of whole numbers, fractions, and decimals, some experience-based geometry, and a few word problems. Furthermore, instruction on each topic is repeated for several years. For example, in a study by Flanders (1987) the percentage of new content in three commonly used text series was calculated to go from an average of 72 percent new content in Grade 1 to 30 percent new content in Grade 8. Thus, for the majority of students mathematics is really arithmetic, and even then the emphasis has been on getting them to master a set of common paper-and-pencil calculation routines consistent with the "low literacy" notions of the common school.

At the secondary school the picture is quite different. First, for the college-bound math-science student there is a four-year mathematics sequence that reflects the traditions of the academy. The sequence includes a year of algebra at Grade 9, followed by a year of Euclidean geometry at Grade 10, another year of algebra at Grade 11, and a year of precalculus work with functions at Grade 12. Students who are planning to go to college but not planning to study mathematics or the sciences, are expected to take two or three years of the same sequence of courses. For students who are not college bound, another year of arithmetic (general mathematics) is usually required. Finally, a few students are accelerated by having them start algebra in Grade 8 and finally take a calculus course in Grade 12.

Enrollment in mathematics courses declines dramatically at each grade level. Estimates of the percentage of enrollment in each course show that, by the time an age group of students has reached high school graduation, about 67 percent have taken an algebra course, 50 percent a geometry course, 30 percent an advanced algebra course, and six percent a calculus course. Another way of summarizing enrollment is that for a particular age group, 10 percent is in an accelerated mathematics track, 20 percent in the science track, 20 percent in the college-prep track, and 50 percent in the general track.

The choice of which topics are to be taught in mathematics classes is deliberate, but how the decisions are made is not clear. The topics that are taught are those that appear in the textbooks used, and what is emphasized is usually those concepts and skills that appear on tests. But who decides on those texts and tests? Procedurally the decisions are made by local school boards, all 15,000 of them. In actuality the decisions are influenced by curriculum developers, administrators, political pressure groups, publishers, and others interested in what is taught in schools. The usual pattern involves a school district adopting a curriculum framework, then examining a set of texts and tests that can be shown to cover the topics in the framework, and selecting from that set. Of course, although there are over 500 producers of educational material in the U.S., only a few texts and tests gain wide acceptance. In fact, because of state adoption policies in a few large states (in particular, California, Texas, and Florida), wherein districts select texts from the state approved list and the state pays for their purchase, only a few (often very similar) texts dominate the market nationwide. The stereotypic view that is represented in the texts and tests is that mathematics is a static, bounded discipline that students are expected to learn in a fixed sequence.

7.3.3 The Job of Teaching

Currently the primary work of teachers is to maintain order and control (Romberg and Carpenter, 1986). There is an inexorably logical sequence when the acknowledged work of teachers is to transmit the record of knowledge; the most cost-effective way to accomplish this is through exposition to a captive audience. (Theoretically a child could cover the same ground by reading, but that would require a voluntary act, which is unlikely as long as children are not setting their own goals.) And that exposition cannot happen unless there is control, which is easier if children talk as little as possible and stay in one place. It is essentially a system for "delivering" knowledge to the group by controlling the individual. This simple sequence has dictated work, furniture arrangement, architecture, and so on for the last hundred years, and it is this tradition that must be challenged by any attempt at change. The traditional classroom focuses on competition, management, and group aptitudes; the mathematics taught is assumed to be a fixed body of knowledge; and it is taught under the assumption that learners absorb what has been covered (Romberg and Carpenter, 1986, p. 868).

The following remarks from one of the NSF case studies of mathematics teaching describe a typical day of instruction:

> In all math classes I visited, the sequence of activities was the same. First, answers were given for the previous day's assignment. The more difficult problems were worked by the teacher or a student at the chalkboard. A brief explanation, sometimes none at all, was given of the new material, and problems were assigned for the next day. The remainder of the class was devoted to working on the homework while the teacher moved about the room answering questions. The most noticeable thing about math classes was the repetition of this routine (Welch, 1978, p. 6).

During the past quarter century, because of concerns about trying to get teachers to adopt and use new programs, there has been a tendency to overspecify instructions for teachers. Both the detailed individualized programs and the highly structured group programs deprive teachers of the opportunity to develop important teaching skills. Often they no longer make decisions about what activities to use. Taken to an extreme, the teacher becomes only a conduit in a system, covering the pages of a program without thinking or consideration.

The working conditions of teachers in the U.S. are not comparable to those enjoyed by teachers in many other countries, either. American teachers have little time to reflect on their practice; they are not expected to work regularly with other teachers on curricular plans or lesson development; and they are not provided with adequate support services.

In summary, the teaching of mathematics in the U.S. has been viewed as a trade, involving personal management skills. Too many American teachers are not treated as professionals.

7.3.4 Activities of Students

When knowledge is regarded as knowing about rather than knowing, the work of the teacher is to "transmit" knowledge. Logically this means that the job of the student is to receive it and regurgitate it on demand. Even worse, the real work of the student is often a matter of negative goals, meeting expectations sufficiently to pass through the system (Skemp, 1979). The situation described above is typical of American classes — organized, routine, controlled, and predictable — an unlikely environment for the creation of knowledge. Most current mathematics programs in the U.S. have conceived of the learner as being a passive absorber of information, storing it in memory in little, easily retrievable pieces. This view of learning is consistent with the fragmentation of mathematical content as it has been presented routinely in the schools in this country.

This conception of learning is based on the tenets of "behaviorism," a theory that evolved during the early part of this century. The theory actually focuses on the outcomes of learning (behaviors) rather than on how learning occurs. It assumes that learning occurs by passively — but rationally — reflecting on stimuli from the environment. It has been used by scholars to study how desired responses to stimuli (outcomes) become fixed by practice and praise (reinforcement). Learning is viewed as a change in behavior (or performance), and changed scores (pretest-posttest differences) on some measure of performance are often used as evidence for learning. This theory, in its many forms, has strongly influenced all education in the United States and, in particular, school mathematics. Its strength lies in what Schrag (1981) has called its "generative" characteristics. By this he means that the theory has generated a number of practical procedures that can be used in schools.

7.3.5 The Industrial Model

This stereotype of school mathematics in the U.S., as described above, is not at all complimentary. Mathematicians and mathematics educators have been attempting to change the system since the turn of the century, with little success (Stanic, 1986). The reason change has been so difficult is that the traditional school is a coherent structure organized to accomplish its objectives. Its structure was developed in a different era. It grew out of the machine-age thinking of the industrial revolution of the past century. The intellectual contents of the machine age rested on three fundamental ideas: The first was reductionism. The machine age was preoccupied with taking things apart. The idea was that in order to deal with anything, you had to take it apart until you reached its ultimate parts. The second fundamental idea was that the most powerful mode in thinking was a process called analysis. Analysis is based in reductionism. It argues that if you have something that you want to explain or a problem that you want to solve, you start by taking it apart. You break it into its components, you get down to simple components, then you build up again. The third basic idea of the machine age has been called "mechanism." Mechanism is based on the theory that all phenomena in the world can be explained by stating cause-and-effect relationships. The primary effort of science was to break the world up into parts that could be studied to determine cause-and-effect relationships. The world was conceived of as a machine operating in accordance with unchanging laws.

These ideas gave rise to what has been called the first industrial revolution. In this world, work was conceived of in physical terms, and mechanization was about the use of machines to perform physical work. Man was supplemented by machines as a source of energy. Man-machine systems were developed for doing physical work in such a way as to facilitate mechanization.

This whole process is clearly reflected in what has happened in school mathematics during the last half century. Mathematics was segmented into subjects and topics, eventually down to its smallest parts — behavioral objectives. At this point a hierarchy was created to show how these components were related and eventually produced a finished product. Next, the steps by which one traveled that hierarchy were mechanized via textbooks, worksheets, and tests. Furthermore, teaching was dehumanized to the point that the teacher had little to do but manage the production line. Businesses, industry, and — in particular — schools have been conceived and modified based on this mechanical view of the world.

Like the Model T Ford assembly line, current models of schooling were considered an example of the application of modern, scientific techniques. Today we ought to be able to develop better school mathematics programs.

My intent in this section has been to reflect on the current status of mathematics in American schools. My hope is that all teachers and staffs come to see that the reform arguments involve more than changing what is taught in mathematics classes. They challenge the traditional assumptions about schooling. Only by situating changes in what mathematics is taught and how it is organized in this larger perspective about reform of schooling will such changes be lasting.

7.4 What Content and Organization Are Being Advocated?

Being able to demonstrate that a genuine need exists is necessary to justify change, not necessarily to guarantee good outcomes. Satisfying the need will only be possible if there are demonstrated connections between need and the proposed curricular changes. A goal for any teacher enhancement program should be to confront teachers with the task of considering what mathematical content is to be included in the curriculum and how it should be organized. In fact, whether it occurs as a part of a teacher enhancement project or not, all educators are currently, and will continue to be, pressured by policy makers to redefine the content to be included in the school curriculum (content standards), how it should be taught (delivery standards), and how it should be assessed (performance standards). The nation's governors and the federal administration have made the development of such standards in English, mathematics, science, history, and geography the priority for school reform. At issue is the degree to which teachers are active participants in developing such standards and the degree to which teachers understand and can use such standards documents in making curricular decisions.

The common problem now being faced by many school mathematics staffs is how should they respond to the facts that

1. They have received copies of *Curriculum and Evaluation Standards for School Mathematics* (1989) and *Professional Standards for Teaching Mathematics* (1991) from the National Council of Teachers of Mathematics. (These documents are being taken as exemplary models for content and delivery standards by the U.S. Department of Education.)

2. Within their state they are being faced with a new state curriculum framework based on (or related to) the NCTM's *Standards*.

3. Publishers of mathematics textbooks and tests are now claiming that their products "meet the *Standards*."

4. The National Science Foundation is supporting the development of several new mathematics curricula that reflect the reform vision.

My intent in this section is to acquaint teachers with some of the underlying ideas involved in what the mathematical sciences education community now sees as the desirable content and organization of a school mathematics curriculum. The next three parts parallel the sections in the last section: "What it means to know mathematics," "activities of students," and "the job of teaching." Note that the order in which ideas about "teaching" and "students" are considered is reversed from that in the last section. This is deliberate; it reflects a major shift in thinking about school mathematics. This is done so that the contrast with current practices is apparent. In the final part, I illustrate what these changes mean with respect to one mathematical domain: "ratios."

7.4.1 Changing Views about Knowing Mathematics

The most important feature of the reform arguments involves a shift from the practice of having students master a long list of concepts and procedures to encouraging them to regard mathematics as a means of making sense of common and complex situations. The contrasts between this emerging view of mathematics and older views has been summed up by Robert Davis (1992, p. 226) as follows:

Previous view	**Newly emerging view**
"Mathematics" is about **symbols written on paper**.	"Mathematics" is **a way of thinking** that involves **mental representations** of problem situations and of relevant knowledge, that involves dealing with these mental representations, and that involves using heuristics. It may make use of written symbols (or even physical representations with manipulatable materials), but the real essence is something that takes place within the student's mind.

The new view of mathematics shifts the emphasis from symbols and their manipulation to realistic situations that give meaning to such symbols and the rules for their use. This shift is reflected in the NCTM's *Standards*, which argue for a reduced emphasis on arithmetic computation, especially mastery of complex paper-and-pencil algorithms, and instead advocate a focus on the meaning and appropriate use of operations, judging the reasonableness of results, and choosing appropriate procedures.

To illustrate how this emerging view of mathematics is being transformed into curricular units, I have chosen to concentrate on three notions: "maths," not math; "story-shell units," not chapters; and "integration of units," not courses.

"Maths," not math. "Mathematics" throughout most of the world has always been considered a plural noun. Rather than organizing mathematics into courses by traditional subject labels (e.g., arithmetic, algebra, geometry), the content in a new curriculum should be organized in terms of several domains, with units to be built around those domains and then integrated into courses. Some of the domains are

- counting and numeration
- measurement
- whole numbers
- estimation
- quantities (common fractions, decimal fractions, ratio and proportion, and integers)
- synthetic geometry, algebraic geometry
- statistics and probability
- algebra
- patterns, relations, and functions
- discrete mathematics
- calculus
- mathematical structure

These domains should not be considered independently of one another. While it is true that each domain has some unique properties (signs, symbols, rules), activities should focus on problem situations, which provide students with opportunities to rethink, reread, investigate assumptions, and so forth. Note that this list of domains contains mathematical topics that are seriously underrepresented in current curricula but are now considered increasingly important: geometry, measurement, probability and statistics, algebra, patterns, relationships and functions, and discrete mathematics. This content emphasis is supported in several recent documents that describe mathematics in these terms: "Ordering the Universe: The Role of Mathematics" (Jaffe, 1984), "The Science of Patterns" (Steen, 1988), *Reshaping School Mathematics* (MSEB, 1990a), *On the Shoulders of Giants* (MSEB, 1990b), "Problematic Features of the School Mathematics Curriculum" (Romberg, 1992).

"Story-shell" units, not chapters. To transform the vision of maths into educative work for students, most of the new NSF-supported curriculum projects have adopted a strategy of constructing instructional units that take three to five weeks to teach and each of which is rooted in a context or tells a story. Students are expected to construct meanings, interrelate concepts and skills, and use those meanings in a variety of related problem situations. The units should be similar to a chapter in a Dickens novel: each unit should introduce or reintroduce the characters to the reader, and there should be a new problem situation to be resolved that involves conflict, suspense, crisis, and resolution. The belief is that students should be exposed to the major conceptual domains as these arise naturally in problem situations. Ideas are best introduced when students see a need or reason for their use. The situations must be authentic (i.e., situations in which people actually use mathematics to enable them make sense of the problem). Problem situations may include the historic reasons for the development of a mathematical domain, the relationship of that domain to other domains, or the realistic use of that domain. Also, some of the contexts in which problem situations are posed should be culturally relevant so that they give each student an opportunity to develop democratic attitudes.

Curriculum units should always be considered as incomplete, however. All curriculum sequences need to be adapted and modified in light of the knowledge that students bring to the unit and the context in which instruction takes place. What actually occurs will differ among classrooms. No program can be "teacher proof." Instead the program should assist each teacher in making reasonable adaptations so that the prior knowledge and interests of the students are taken into account in instruction.

"Integration of units," not courses. All of the currently funded NSF curriculum projects are now developing curriculum units targeted for a wide range of students. For example, the *Seeing and Thinking Mathematically* project for Grades 6-8 is creating a series of units. The unit "Designing spaces for people" expects students to build a model house to meet various constraints (Kleiman, 1992). A unit titled "The overland trail" is similar to others being developed by the *Interactive Mathematics Project* for Grades 9-12 (Alper, Fendel, Fraser, and Resek, 1992). Similar units are being developed jointly by the staffs of the National Center for Research in Mathematical Sciences Education and the Freudenthal Institute for the Grades 5-6

Maths in Context curriculum — e.g., "wet and dry numbers" (Romberg, Allison, Clarke, Clarke, Pedro, & Spence, 1991).

The expectation is that school committees and teachers will select and adapt units such as these to form a complete curriculum for their students. The units chosen undoubtedly will vary from school to school and teacher to teacher. It is expected, however, that the choice of units will be made using criteria such as balance across mathematical domains, natural cross-curricular connections, opportunities for all to participate, and opportunities to extend problems.

7.4.2 Activities of Students

The work roles of students and teachers are complementary (Skemp, 1979); some teach, the others learn. Since schools are ostensibly places where students gather to learn, however, the role of the teacher should complement that of the student, rather than vice versa. Davis (1992, p. 227-228) has contrasted the emerging view of acquiring knowledge as follows:

Previous view	**Newly emerging view**
Knowledge of mathematics is constructed from words and sentences (and usually sentences about what to write on the paper, and where to write it).	These critical mental representations are built up from pieces learned as a result of previous experience. This often means concrete experience, but it does not always mean this. One kind of "piece" is often called an **assimilation paradigm**. The key pieces of mental representations are usually *not* about written notations — they are not about symbols, but rather about the things denoted by the symbols. The mental representation of a seven-foot-tall man is not primarily about the numeral "7," not about the three-letter word "man," but rather about a very tall male human being (maybe a basketball player?). *Words* may be used, primarily to guide the construction of mental representations, but the mental representations themselves are *not* built out of words. If I say "dog" I may cause you to think of something, but in most cases what you think of will not be the three-letter word "dog."

The point of learning mathematics is to learn a few facts (such as "3 times 4 = 12"), a few standard algorithms for writing symbols on paper, and a few definitions. The point of advanced mathematics is to memorize a few proofs. In both cases, the goal is conformity to a prescribed orthodoxy — one wants students to write the standard algorithm in the standard way.	The goal of studying mathematics is to learn to think in a very powerful way, as described above.
Students would not be able to invent algorithms themselves.	Students often invent their own algorithms, even though they may try to conceal this from the view of adults who would probably disapprove.

To capture the importance of knowing mathematics, the term *mathematical power* has been used to indicate the quality of mathematical literacy sought. This perception of mathematical power envisions a citizenry and society empowered by mathematics. Mathematical power for the individual means that a person has the experience and understanding to participate constructively in society. Over the ages, people have invented and used mathematics to count, measure, locate, design, play, conjecture, and explain. They have also examined its generalized abstractions and developed out of them further mathematics — explanations, designs, proofs, or new theorems — that may or may not have had practical applications (Bishop, 1988). People are continuing to do all of these things, but in a rapidly increasing variety of contexts, in increasingly complex situations, and with shorter and shorter time spans for development. For a culture to be mathematically powerful, its citizens must have the mathematical understanding and experience to undertake the routine tasks of everyday life, operate as a democratic society, and progress as a civilization. This means the acquisition, in society, of a critical mass of understanding and experience, in addition to the availability of a substantial range of special expertise.

The NCTM *Curriculum Standards* presented four basic standards to be applied to all of the other content standards: *mathematics as problem solving*, *mathematics as reasoning*, *mathematics as communication*, and *mathematical connections* (making linkages within mathematics and between mathematics and the real world). These are statements about valued expectations. As such they should be read as recommendations for action.

Mathematics as Problem Solving. As students use this method of inquiry in approaching mathematical content, they learn to formulate problems and develop and apply cognitive strategies to their solution, both within and outside mathematics. In a range of contexts, they verify and interpret results and generalize solutions to new problem situations. In addition they should provide students with an opportunity to act according to insight and democratic attitude. In this way, students have an opportunity to develop the capacity for reflective thought necessary for democratic citizenship. In developing skills for reflecting, they learn to apply mathematical modeling and become confident in their ability to address real-world problem. As they reason through problems, students develop the habit of making and evaluating conjectures and constructing, following, and judging valid arguments. In the process they deduce and induce; apply spatial, proportional, and graphic reasoning; construct proofs; and formulate counter-examples.

Mathematics as Reasoning. Problem situations encourage students in the purposeful investigation of situations that are open to multiple approaches. Students need experience in a range of prototypic situations so that they can analyze their structure, finding essential features and the ways in which aspects are related. In this context *prototypic* is meant in three ways: (1) a situation may be representative of the kind of cultural context that has traditionally given rise to mathematics (Freudenthal, 1983), (2) a situation may be familiar in the context in which it is presented to the student, and (3) some situations should address current social and political problems for which mathematical notions are (or can be) used to help make sense of the problem (see de Lange, in press, for a detailed description of the variety of situations one would consider). For such situations, students need to be able to pose a question, see the next question, evaluate a strategy, and construct and discuss alternative methods. Having done so they can then examine assumptions and arguments and make reasoned choices.

To produce a worthwhile result, students may need to judge what data are required and then gather, process, and evaluate those data. They may also need to develop examples by which to test conjectures. If the evaluation is unsatisfactory, they may have to reconsider what they have done. This suggests the need for fluency with notational systems, the ability to develop abstractions and explain clearly, the capacity to appreciate another's point of view, and a readiness to arrive at a shared understanding.

Mathematics as Communication. Communication is essential to mathematically powerful individuals. In communicating with others about the problems in which they are engaged, students develop the power to reflect on, evaluate, and clarify their own thinking; model situations; formulate definitions; and express ideas. In the process they discuss their conjectures with others and develop the power to make convincing arguments; to read, listen, and view with understanding; and to ask extending questions. Ultimately their power to communicate will be judged by their versatility, fluency, and elegance in choosing, using, and switching between representations that both best symbolize the mathematical ideas under discussion and are most appropriate to their audience.

Mathematical Connections. This term emphasizes a belief that although it is often necessary to teach specific concepts and procedures, mathematics must be approached as a whole. Concepts, procedures, and intellectual processes are interrelated. In a significant sense, "the whole is greater than the sum of its parts." Thus, the curriculum should include deliberate attempts, through specific instructional activities, to connect ideas and procedures among different mathematical topics with other content areas and to issues beyond the classroom.

7.4.3 The Job of Teaching

The work of teachers must complement the work of students. Again, Davis (1992, p. 227), in his contrast of the newly emerging view of mathematics education with previous views, has characterized the shift as follows:

Previous view	**Newly emerging view**
"Teaching mathematics" means getting students to write the right thing in the right place on the paper.	"Teaching mathematics" is a matter of guiding and coaching the student's own development of his/her repertoire of basic building blocks (from which mental representations can be constructed), and helping students to develop skill in building and using mental representations.

In the new view ,teaching is not lecturing but creating a discourse community where ideas are shared, discussed, accepted, or discarded.

7.4.4 An Example: "Ratios"[1]

For most people, a ratio is an expression of a relationship between two quantities (a:b). For example, comparisons can be made between death rates per state, number of children per family, or number of students per teacher. And for most people a proportion is merely a statement of the equivalence of two or more ratios (a:b = c:d). Furthermore, most textbook problems that present three of the four quantities in a proportion ask the student to find the remaining quantity. Unfortunately this emphasizes "cross multiplication" as a means for finding the other quantity, rather than a ratio as a means of expressing relationships: this limits one to using a procedure without understanding it.

Ratio and proportion. This is an important domain for several reasons. First, many scientific relationships can be expressed as ratios (e.g., distance traveled:average rate). Second, ratio and proportion allow one to analyze the relation of part to whole. One can, for example, analyze part of an area or part of a population. Also, because of its relationship to functions, proportional reasoning — a term used to capture the breadth of the ratio and proportion domain — is an important underpinning for algebra, trigonometry, geometry, probability and statistics, and calculus. In addition, the concept of ratio and proportion can be found in many other areas, such as economics, agriculture, art, and sports. Thus it is a topic that permeates many aspects of life.

Although most middle schools cover ratio and proportion at some point, students often do not understand or retain what they have been taught. For example, the Second International Mathematics Study indicated that the items relating to proportional reasoning were very difficult for American eighth-graders, and that the number of items answered correctly at the end of the year ranged from a low of 16 percent to only 66 percent (Travers and Westbury, 1989).

The Standards suggest that students be given many opportunities to understand and apply ratio and proportion. They recommend that students be introduced to ratios through situations in which ratios occur naturally. For example, they pose the following problem:

> If 245 of a company's 398 employees are women, how many of its 26 executives would you expect to be women? (NCTM, 1989, p. 89)

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[1] *This example has been adapted from the* Blueprint for Maths in Context *(Romberg, et al.,1992).*

Note that finding the answer to this question should lead the students to discuss not only how the answer could be found, but whether the answer reflects reality, and if not, why not?

Cognitive development of the domain. The topic of ratio and proportion requires a long-term process of "progressive mathematization," not as a discrete educational unit, but as an exercise in addressing the ideas embedded in an integrated curriculum. Students can obtain a better understanding of ratio and proportion if they are allowed to participate, throughout several years, in planned experiences that reintroduce the topic at increasingly demanding levels. Therefore, teachers should go beyond formal definitions and textbook-type problems. They should give students opportunities to use proportions in everyday experiences while allowing them to build on their intuitive knowledge as they progress to higher levels of thinking. Furthermore, students need to have experiences with ratios that represent a variety of contexts. Variety is necessary so that understanding becomes divorced from any one context and generalized beyond the context in which it was learned. Students should come to realize that the numbers in the problems are not sufficient, in and of themselves, to determine the answer. The relationship between the numbers is of vital importance, and this relationship can only be derived from the context of the problem.

Connections to functions. A ratio is a simple linear function that can be written in the form $y=mx$ (where m is a constant). It is not necessary, however, for the student to use functional notation in order to work with these problems and to understand the multiplicative relationship involved. Because of their simplicity and their use in real-world contexts, ratios are a natural bridge between numerical patterns and functions.

Differences between ratios and common fractions. Although ratios and common fractions often share a basic symbolism and the rules governing computation, they are conceptually different. There are three critical distinctions between common fractions and ratios:

- Part-whole fractions compare quantities referring to the same item. Ratios may compare quantities of different objects that have been measured in different units. For example, a ratio may compare miles to hours.

- Common fractions are always rational numbers. Ratios are sometimes irrational numbers. For example, the ratio of a circle's circumference to its diameter is an irrational number.

- When the denominators are the same, fractions are combined by adding numerators. Ratios, however, are frequently combined in a different manner — for example, 4 hits in 7 turns at bat followed by 3 hits in 7 more turns at bat is 7 hits in 14 turns at bat (4:7 + 3:7 = 7:14).

Students should be exposed to ratio problems that bear out these distinctions. They should realize that although ratios may look like and in some cases be manipulated as, fractions, ratios and fractions are two different mathematical concepts.

Methods of solving ratio and proportion problems. The results of the Concepts in Secondary Mathematics and Science study (Hart, 1981) indicated that when students were asked to solve proportion problems, they used some form of addition strategy. Thus, students did well on problems where the answer could be found by doubling or tripling numbers in the ratio. Students did less well, however, on those problems where they were required to use a multiplication strategy to solve the problem.

Similar results were found in the National Assessment of Educational Progress (Lindquist, 1989). Only about half of the eighth-graders were able to solve the following problem:

> The ratio of boys to girls in a class is 3 to 8.
>
> How many girls were in the class if there were 9 boys?

Many students used an incorrect strategy and answered 14. They evidently thought that since 9 is 6 more than 3, then 14 would be 6 more than 8. In other words, they failed to recognize that a multiplicative strategy was necessary to solve this type of problem.

In planning a curriculum, the unique features of each content domain need to be described in similar detail, the relationships of each domain to other domains explained, and the known measures of student performance identified. Such information is necessary as a basis for creating a more challenging curriculum.

In summary, the newly emerging version of a school mathematics curriculum pictures radically different context and organization. The description of, and rationale for, this curriculum have gained wide acceptance within the mathematical sciences community. But it is a "vision," not a "recipe." Reform can only be realized by those prepared to take the next steps in the reform process.

7.5 How is the Mathematical Sciences Education Community Planning to Implement These Changes?

The emphasis in this chapter is on the problem of curricular change in school mathematics. I am suggesting a strategy that school districts and schools should consider as they construct a curriculum in line with the current reform movement. The strategy rests on the assumption that real change cannot be imposed but must be created by all who are being asked to implement the change. Since education is a human process, one must involve students, parents, teachers, administrators, policy makers, and the public at large in any effort to effect educational change. Only by involving everyone implicated in the schooling process in a substantial way can consensus be reached about the need for change, the direction of change, and the means of planning for those changes. Since school staffs, and in particular mathematics teachers, are the ones who must implement the changes in the mathematics curriculum, they must be the problem solvers.

7.5.1 Steps to Be Followed

Figure 7-1 (adapted from Boyer, 1991) contains seven related steps of an iterative strategy that members of the mathematical sciences education community have been following in their attempt to bring about reform in school mathematics.

The relationships between the steps shown in Figure 7-1 are as follows:

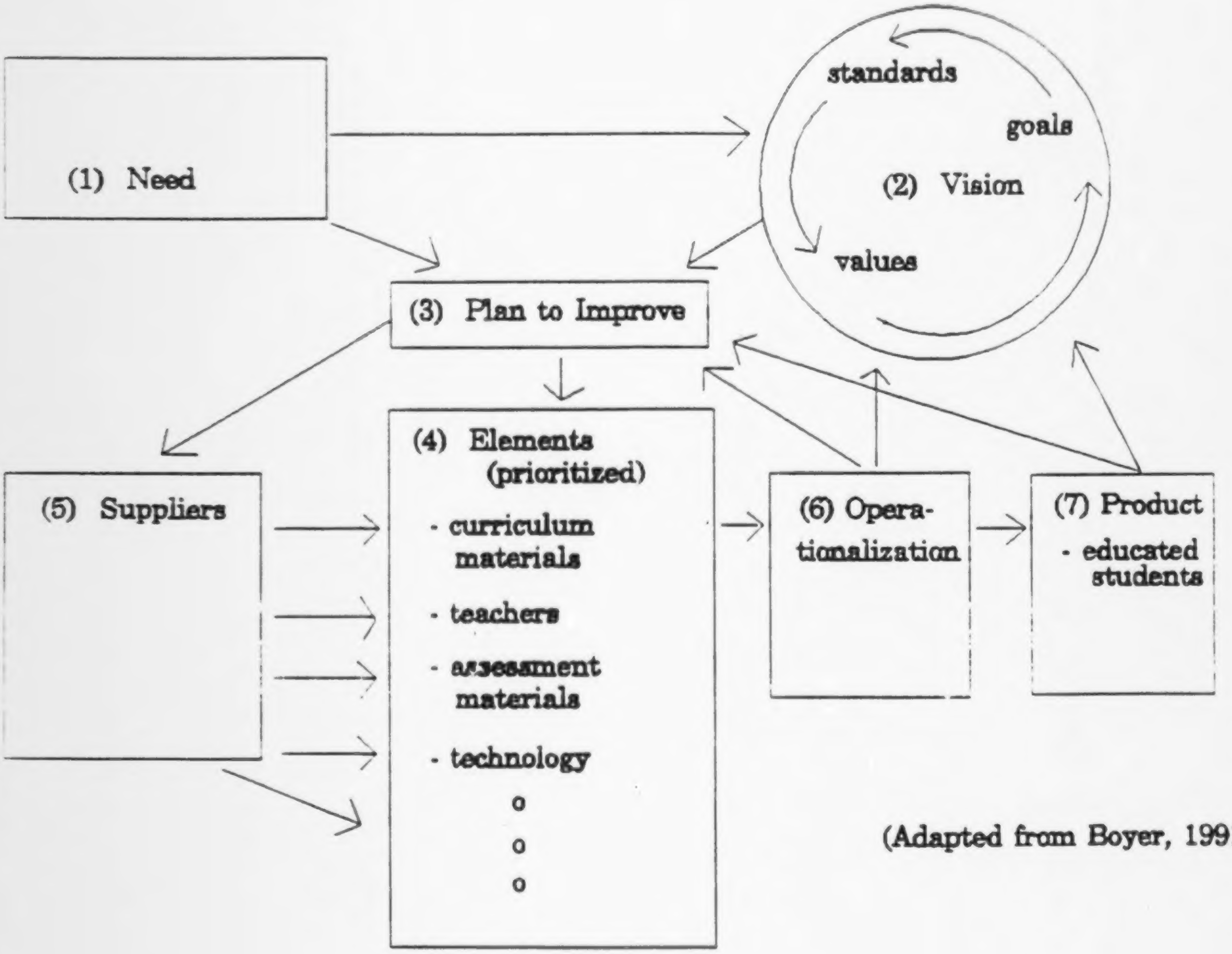
1. *Need*. Before any change plan can proceed, one must establish a need for change. To do this, two things must be considered. First, evidence must be presented that the current system is not working — a defensible end is not now being adequately served (Scriven, 1977). And second, if a new design is needed, planners must be aware of the traditions that need to be challenged. I have tried to present background information on these in sections 7.2 and 7.3.

2. *Vision*. This is a key factor if a new design is needed. Design change involves not only eliminating inadequate materials or practices, or replacing them, but also designing a new system. One must consider the features of the new design and be able to argue that they satisfy the need. Good intentions are not enough. Specifying a vision necessarily will include consideration of values, goals, and standards. The basic elements of this have been described in section 7.4

3. *Plan*. This step involves everybody in a system or a school arriving at consensus about the details of both a long-range and short-range plan (with timetables) for carrying out the needed changes.

Figure 7-1

Steps of the Quality of Reform Strategy.


(1) Need
standards
goals
(2) Vision
values
(3) Plan to Improve
(4) Elements (prioritized)
- curriculum materials
- teachers
- assessment materials
- technology
o
o
o
(5) Suppliers
(6) Operationalization
(7) Product
- educated students

(Adapted from Boyer, 1991)

4. *Elements*. Involved in this step are the identification of specific elements of the system to be targeted for change (e.g., curriculum materials, instructional methods, examinations, teachers, technology) and their prioritization.

5. *Suppliers*. Any system depends on suppliers. In a "supply and demand" society, schools must demand that suppliers (e.g., textbook publishers, testing companies, staff developers, university teacher education programs) produce the materials necessary for the desired changes.

6. *Operationalization*. At this step one tries out the new materials, procedures, and programs. Feedback from this trial is matched with the vision and the plan for judgment, and iterative revisions are made.

7. *Products*. At this final step, one produces a product (e.g., a new curriculum, instructional procedure, assessment materials). In economics, a product is judged of good quality if it satisfies customer needs and at the same time makes the company a profit. In education, the quality should be judged in terms of what students are able to do and whether this meets society's needs.

The educated student is the product of schooling. Via feedback, one again returns to the vision and plans to update or revise the vision, plans, and specific elements.

I propose here that this change strategy be understood and followed by school staffs at all levels to develop a reform curriculum for school mathematics for K-12. In particular, the objective of any staff development program should be to help teachers see that they have a critical role in the reform efforts and that empowering them to take that role is a vital goal of all teacher enhancement programs. Each teacher must understand the need for change, own the vision, be an active participant in the planning process, become a spokesperson for the demands for new products and processes, be involved in trying out new materials, and judge student progress toward the reform vision.

Teacher enhancement programs need to focus on the teachers' role in the planning process for curriculum reform. The chapter in this volume by Thomas J. Cooney addresses this issue in detail. Since teachers are to treat students as social constructors of knowledge, staff developers also must treat teachers as social constructors of knowledge. Teachers cannot be handed others' solutions to problems. They must be empowered to assist in the planning and creation of solutions. To do this, teachers must be confronted with problems, sources of information, materials, and challenges to current practices, and then be expected to plan collaboratively to solve those problems.

7.5.2 Principles

The following principles are targeted at the local curriculum committee level, where, I believe, most important decisions about elements, resources, and supplies occur. The mathematical sciences education community made the following recommendation in *School Mathematics: Options for the 1990s*:

> ***Recommendation 9:*** In each school or school district, a school mathematics committee should use the curriculum guidelines [standards] and staffing recommendations to outline the curriculum and provide support for the mathematics program. (Romberg, 1984, p. 3)

The principles are a product of the conviction that such a curriculum committee, through reflection and discourse, is best able to plan changes. It is at this level that local needs and conditions can be addressed. If it is assumed that learning depends on active participation, then the program must be a program of activities from which knowledge or skills can be developed. Simply developing a series of interesting activities is not sufficient, however. The knowledge gained must lead somewhere. This means that what is constructed by any student depends to some extent on what the student brings to the situation, where the current activity fits in a sequence, and how it relates to mathematical power. Thus the suitability and effectiveness of selected learning activities is an empirical problem. It depends on the student's prior knowledge, level of reasoning, and expectations. These can only be determined by staff at the local level, using the following general principles. (While these principles are written for local curriculum committees and teachers, the same issues must be considered at the other levels.)

> ***Principle 1.*** *A school mathematics curriculum committee should be formed with representatives from a wide range of those interested and involved in the teaching and learning of mathematics.* Only through dialogue and discourse among all parties can consensus on both short-term and long-term plans for reform be reached. Along with mathematics teachers at all school levels, the committee should include administrators, counselors, board members, parents, and community members.

> ***Principle 2.*** *The committee should take time to read and reflect upon the reform documents before establishing plans.* Changing schooling practices is complex and difficult. Only if those involved both understand the need for reform and make a commitment to the reform vision will they be able to create an informed plan with some probability of success.

> ***Principle 3.*** *The curriculum plan developed by the committee should begin its task by focusing on mathematical domains.* Controversies about the teaching of mathematics cannot be resolved without confronting issues about the nature of mathematics. Only by examining the details of mathematical domains (such as that of ratio and proportion) can consensus be reached about what to emphasize, what kinds of activities to include, and so forth.
>
> ***Principle 4.*** *Planning must involve both short- and long-term plans and a prioritization of elements to be addressed.* Effecting change in schooling practices must be seen as a long-term effort. The planning committee should recognize that implementing a vision in a reasonable way will take at least a decade. After they come to understand the need for reform and have developed and become committed to a reform vision, however, work can proceed on changing elements of the system. Priorities should be determined by building on the strengths of the school staffs and the resources available from suppliers and within the community. For example, if the teachers in a given school consider themselves to be knowledgeable about ratios, instructional activities available from publishers and business members in the community can provide many interesting examples of how ratios are used. Ratios would then be a domain that might receive a high priority for reform.

Curricular planning at the school level is critical if design change is to occur. Unfortunately, such planning is far from common in American schools. This discussion of planning *curriculum change strategies* should make it plain that the next four steps in the change strategy discussed above (elements, suppliers, operationalization, and judgment of products) are necessary consequences of this step. Teachers' need for types of materials, texts, tests, and staff development must be expressed and responded to in light of the plans. Teachers need to make the suppliers of such materials and services cognizant of their demands. Teachers must be encouraged to be experimenters with new materials and procedures. And teachers must be participants in the process of judging the value of the materials and procedures for student growth. Furthermore, the steps in the change strategy are iterative steps in a systemic view of change over time, and teachers are the key participants in all of the steps.

7.6 What are Some of the Issues and Problems Reformers Will Face?

As implied in this chapter, the implementation of the vision of a reformed school mathematics curriculum involves nonroutine activities for policy makers and school staffs. To carry out the proposed curriculum change strategy, the participants will be faced with a number of issues and problems. The philosopher Karl Popper (1968) once argued that in the social sciences, traditions served a role similar to laws in the sciences: They are assumed to be true until proven false. As such, they bring order and predictability to everyday life. Unfortunately, we usually accept traditions uncritically, often without being aware of it. For an approach to change to be successful, one must critically challenge several traditions of how mathematics is considered, organized, and taught.

7.6.1 Curricular Traditions

There are several issues related to the traditions about what mathematics is taught and how it is organized.

What is mathematics? "Most of the population perceive mathematics as a fixed body of knowledge long set into final form. Its subject matter is the manipulation of numbers and the proving of geometrical deductions. It is a cold and austere discipline which provides no scope for judgment or creativity" (Barbeau, 1989, p. 2). This view of the discipline is undoubtedly a reflection of the mathematics studied in school. A dynamic view of mathematics on the other hand, has powerful curricular consequences. The aims of teaching mathematics need to include empowerment of learners to create their own mathematical knowledge; reshaping of mathematics, at least in school, to give all groups more access to its concepts and to the wealth and power its knowledge brings; and bringing the social contexts of the uses and practices of mathematics into the classroom.

The "saber-tooth tiger" content problem. Topics should be included because of their inherent worth, not because they have "always been part of the curriculum." Peddiwell's (1939) satirical tale of continuing to teach students techniques to scare the extinct saber-tooth tiger with fire is analogous to the continued expectation that students should master interpolation of logarithms, square roots, long division, and a myriad of other routine procedures long after computers have automated such procedures.

How can we be sure students will develop basic skills? The definition of basics is changing and must change. Basic skills are now more broadly defined and include the ability to solve real problems, reason, make connections, and communicate mathematics. The traditional curriculum has resulted in few students able to do these important things. There is little value in a student being able to multiply two decimals with pencil and paper if the same student is unable to recognize a situation that requires this skill and to use it appropriately.

Traditional mathematics teaching has emphasized computation to such an extent that students spend little time actually using the mathematics they have learned. It is like having an impressive toolbox and knowing how to hammer, but having no idea when the hammer is the appropriate tool to use.

Is the reform vision of school mathematics world-class? In a recent study, curricular expectations across eight countries were compared with those presented in the *Standards* (Romberg, et al., 1991). The study found that

- The *Standards*, when compared with the national curricula of other countries, do not represent a "radical" or "romantic" vision of school mathematics.

- The manner in which each country builds a detailed rationale for these reforms and, specifically, which changes are emphasized, depends on their past practices. The *Standards* focus on the need to include many other aspects of mathematics each year in an integrated curriculum. Since this has long been the tradition in other countries, such within-discipline integration is not mentioned in their reports. Other countries tend to emphasize the shift from the formal aspects of mathematics to modeling and realistic applications.

- The four standards — problem solving, communication, reasoning, and connections — in the NCTM's *Standards* are reflected in all eight national curricula studied.

- The variation in emphasis with respect to particular mathematical topics is related to past cultural practices in different countries. For example, few documents except the NCTM *Standards* place emphasis on estimating or mental arithmetic in the early grades. In part this is due to the fact that such mental work has long been much more common in other countries, so it did not need to be addressed.

- For Grades K-4, the *Standards*, while including topics new to the American curriculum, still put more emphasis on whole number arithmetic than is found in other countries. This same finding applies to all work with numbers up to Grade 8. There is no standard on "number" for Grades 9-12, however. Other countries appear to be more balanced in their approach to this important aspect of mathematics.

- While geometry is now included at all levels in the *Standards*, it still receives less emphasis in the United States than in the majority of other countries.

- The *Standards* include more emphasis on statistics, probability, and discrete mathematics than other countries.

- Although the beginning notions of calculus are now being suggested for all students in the *Standards*, most other countries have long assumed this to be important and, in fact, expect much more than is suggested by the NCTM.

- Although different programs for students are common in other countries, all students are expected to study mathematics every year they are in school and are often offered several options.

- The curriculum documents from other countries place emphasis on the social, attitudinal aspects of schooling. Schools need to be "a secure environment and place of trust," "social behaviors" need to be taught, "students should realize that mathematics is relevant," "students should gain pleasure from mathematics," and "personal qualities should be nurtured" are common statements in these documents.

7.6.2 Student Activity Traditions

The emerging vision of classroom instruction challenges such traditions as the following:

The "five-step" lesson. The traditional five-step lesson in most mathematics classes (review homework, explain a new lesson, have students work on exercises, summarize, and assign homework) must change. The reform vision assumes lessons will be quite different. This may involve major changes, at least for some teachers, in the conduct and management of classes.

The "hidden" curriculum in schools. Probably the biggest challenge of the reform curriculum for many parents, administrators, and even teachers is its challenge to the routines of school that are based upon existing architecture, organization, and management. Such notions as the following are being challenged by the reform ideas:

- "Math is what we do to quiet kids down after recess."
- "Drill on procedures teaches students how to follow rules."
- "Success on a math test is essential for tracking."
- "Math should not be fun. It teaches students about drudgery and failure."
- "Curricular changes must improve standardized test scores."

7.6.3 The Job of Teaching Traditions

Similarly, many notions about what teachers do must now be challenged:

Teacher independence and isolation. One tradition of schooling is that teaching happens behind closed doors (Metz, 1978). Such independence allows teachers to take risks and be creative. Taken to an extreme, however, independence can and often does lead to isolation. Independence should not be seen as license to be incompetent. Porter (1988) refers to one consequence of independence as a curriculum "out of balance." Elementary school mathematics instruction can be seen as an instruction in which large numbers of mathematics topics are taught for exposure with no expectation of student mastery, where much of what is taught in one grade is taught again in the next, where skills typically receive ten times the emphasis given to either conceptual understanding or application, and where, depending upon the accidents of school and teacher assignment, the amount of mathematics instruction a student receives may be either doubled or halved by comparison with the amount of instruction a student in another context receives.

Will students be properly prepared for the next level of mathematics? Mathematics teachers have long justified to students the teaching of many mathematical topics claiming that "you will need this for the next course." Teaching integrated topics with strange titles, such as "Flying through math" (de Lange, 1992), makes it hard to determine the balance of coverage of mathematical topics.

Can teachers be professionals? The current working conditions of teachers in most schools make it nearly impossible for the typical teacher to be a "professional" (Romberg, 1988). Teachers too often are isolated from issues and ideas in the field and from each other. They have little time to engage in frequent and continuous concrete talk about teaching; nor do they plan, design, research, or evaluate together.

7.6.4 Other Concerns

Although there will be several additional problems and challenges to meet as schools plan and attempt to carry out the reform vision for school mathematics, three other concerns should be mentioned.

Isn't this a repeat of the "new math"? This is a natural question, given the failure of the post-Sputnik attempts to develop a new mathematics curriculum. The answer is: "NO!" The roots of this reform effort are not the same, nor is its vision. The "new math" was an elitist attempt to better prepare college-bound mathematics students for a changed collegiate curriculum, and it was organized by university mathematicians (Romberg, 1990). The current reform movement focuses on mathematics for all students, and it is being organized by teachers of mathematics and others at many levels.

How is this effort related to other current reform efforts? Given the distressing state of education in this country, it is not surprising that there are a variety of current programs in the sciences, social studies, language arts, and fine arts designed to change schooling. Although the effort of the mathematical sciences education community was developed independently from other programs, if scholars in those areas embrace the same assumptions about content and pedagogy that the mathematics community embraced, then they should be compatible. Systemic change based on the same ideas is needed.

Who actually decides on alternatives? This question assumes that choices and judgments will be made in a democratic, rational manner. In reality, one must be aware that such decisions are often based on political or economic considerations.

7.7 Concluding Comments

There is no question that the current school mathematics curriculum is out of date and that the majority of American students do not have an opportunity to become mathematically literate in a culture that is rapidly becoming mathematized. If our students are to be productive workers and reasonable, responsible citizens in the next century, then radical reform is necessary. The mathematical sciences education community has proposed both a vision of a school mathematics curriculum designed to meet the need and a strategy to be followed so that school districts and schools can construct a curriculum consistent with that vision.

The most important aspect of any staff development program is to empower teachers, those who will make the reform curriculum operational in classrooms. Since the construction of a reform curriculum must be operationalized in classrooms, any teacher enhancement program must be designed to help teachers contribute to the solution of design and implementation problems. This means providing teachers more than additional mathematical courses. They must learn how to grapple with such social issues as creating a demand for better materials, textbooks, tests, and working conditions; dealing with the conflicts between long- and short-term goals; knowing how and when to take risks; learning how to collaborate with colleagues; and determining how to operationalize change in their schools. Producing reform curricula will not be easy. It will take time, hard work, commitment, patience, and persistence.

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8 IN-SERVICE PROGRAMS IN MATHEMATICS EDUCATION

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> *At the age of forty-five, with twenty years' experience as a high school mathematics teacher, I thought I was good. My students reported being challenged in my classes and feeling prepared and confident as they went on to various colleges. I had cut my teaching teeth in the sixties on the New Math and had continued to teach the curricula of that era. I decided to take a year's leave of absence to work on my masters' degree in mathematics education -- to make myself a better teacher. Little did I realize what was in store for me.*
>
> *Sue Bingaman*[1]

A basic premise of this chapter is that issues related to conducting in-service programs are far more complex than "giving" teachers more mathematics, pedagogy, or psychology. The real issue is how these "mores" can provide a basis for helping teachers reshape their views about mathematics and its teaching in such a way that they can effectively deal with the difficulties and challenges they face every day in the classroom. While it may be the case that many teachers need to know more mathematics, pedagogy, or psychology, it is also the case that the acquisition of more knowledge by itself is insufficient to ensure change in the classroom. To begin this discussion, a brief review of the status of mathematics teacher education programs is given.

8.1 Issues Related to In-service Mathematics Teacher Education Programs

There is no systematic approach or overarching theoretical perspective that drives most mathematics teacher education programs -- especially at the in-service level. A review of the literature in mathematics teacher education by Fitzsimmons (1991) and Brown, Cooney, and Jones (1990) reveals that few articles provide any quantitative or qualitative basis for comparing in-service programs, nor are there any articles that consider the impact on students of teachers who had participated in in-service programs. Furthermore, the reviews failed to uncover any recently published books that address the improvement of in-service mathematics teacher education programs.

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Although there is a sense that many programs are rooted in a quasi-theoretical perspective that emphasizes learning as a social phenomenon, seldom are the programs' epistemologies made explicit. Often the underlying structures of the programs are described in pragmatic terms. The following description by Larson is typical: "The Mathematics Diagnostic Teaching Program (MTDP) had a heavy emphasis on encouraging the participating teachers to *practice new skills* in their classrooms through the support services of two resource teachers and the enrollment in a one unit practicum each semester" (1990, p. 32, italics added). Given that the goals of the MTDP were "to encourage teachers to teach in small groups rather than large groups" (p. 34), it is not surprising that the results were stated as the percentage of teachers that increased their usage of various aspects of the MTDP program in their classroom teaching.

Similarly, a summer institute described by Graebell and Phillips identified the following goal of the institute: "to improve the teacher's ability to provide meaningful, effective mathematics instruction to elementary school children" (1990, p. 134). The goal was further refined in terms of determining the teachers' mastery of the mathematical content and the extent to which this mastery enabled teachers to change their teaching behavior. Although a key component of the program was based on modeling provided by the instructors, the epistemological basis for the institute was not explicitly clear. An experiment in teacher development by Duckworth perhaps comes the closest to making explicit the theoretical underpinnings of an in-service program, as she focused on helping teachers "develop their understanding of the nature of learning and teaching by having them pay close attention to themselves as learners" (1987, p. 44). Here the emphasis was on teachers reflecting on their own learning processes.

Other mathematics teacher education programs have focused on a variety of outcomes, including the training of teachers to use problem-solving strategies, incorporate the use of technology in their teaching, use cooperative learning groups, and develop better methods of planning for instruction. Indeed, the trail of in-service programs is marked by eclecticism. Given that the history of in-service programs and summer institutes has a long history, dating back to at least 1949 (Meserve, 1989), and that in-service programs are varied in terms of perceived needs and are rooted in a myriad of underlying, usually implicit, epistemological foundations, this eclecticism is not surprising.

Perhaps this is as it should be. Programs are designed to address problems that are particular to a given locale and are embedded in a professional dialogue that is necessarily temporal in nature. This eclecticism makes it difficult to gain a sense of collective wisdom beyond recognizing the bits and pieces that constitute individually effective programs. Nevertheless, Weiss, Boyd, and Hessling (1990) attempted to synthesize outcomes of selected teacher education programs in mathematics and science by surveying project reports and talking with various project directors. It is worth considering some of their findings.

8.1.1 Examining Selected NSF Teacher Enhancement Projects

Weiss, Boyd, and Hessling (1990) divided their assessment of the impact of in-service teacher education programs into two parts: the direct effect of programs on teachers and classes, and the indirect effect — that is, the multiplier effect — of in-service programs that train teachers to have an impact on other teachers. Each of these types of effects are examined briefly.

Effect on Teachers and Classes. The authors found that the projects surveyed had a positive impact on the participating teachers and their students. These ranged from teachers acquiring more mathematical knowledge to their feeling more confident about their learning of mathematics. Weiss et al. (1990) felt that the in-service programs had promoted substantial growth in the teachers' knowledge of mathematics. Although some pre- and post-test data existed, most of the evidence was anecdotal in nature.

Perhaps as a result of this increased confidence and knowledge, teachers indicated that their methods of teaching had become more open-ended. Testimonials from teachers from largely minority or urban schools were particularly encouraging. Most of the testimony focused on the teachers' willingness to move away from the textbook as the sole determinant of the instructional program. The evidence also suggested that girls' consideration of more science-oriented careers improved as a result of instructional programs developed by participating teachers. Also, the programs seemed to have the effect of increasing teachers' professionalism and their desire to stay in the teaching profession.

The Multiplier Effect. Perhaps because of this increased professionalism among the teachers, a fairly substantial second-order outcome emerged. It was reported that projects took on a life of their own and that many teachers developed a certain missionary zeal for the teaching profession. Networking across schools, and involving parents in family math activities, for example, were two of the outcomes that resulted from the in-service programs. Participating teachers indicated they were able to enlist the support of their administrators in changing instructional programs in ways that had not previously been possible. The success of these efforts seemed to be based more on the teachers' perceptions of themselves as professionals than on any formal structure of the outreach programs per se.

8.1.2 Reflecting on Issues from In-service Teacher Education Programs

Despite the efforts of Weiss and her colleagues, it is still the case that the arena of mathematics teacher education, particularly at the in-service level, lacks any kind of systematic analysis. A decade ago, Kilpatrick (1982) came to the following conclusion after analyzing case studies of pre-service and in-service teacher education programs:

> If many of the preservice programs are reminiscent of medical school training -- with their emphasis on an internship experience and their conscious building-up of group cohesiveness and loyalty -- then the in-service programs seem more like medical training clinics in developing countries, where native practitioners are brought in for intensive instruction in new techniques and sent back home to spread the good word. (p. 87)

Kilpatrick's analysis, written more than a decade ago, appears to describe adequately present mathematics teacher education programs.

Nevertheless, things are not the same as they were in the early 1980s. In recent years there has been an emphasis on trying to help teachers increase their use of problem-solving strategies, use cooperative learning groups, incorporate technology into their teaching, and structure their lessons to use class time more efficiently. During this period, proclamations such as *The Nation at Risk* (National Commission on Excellence in Education, 1983) and *Everybody Counts* (National Research Council, 1989) and significant studies on the status of mathematics education such as *The Underachieving Curriculum* (McKnight, Crosswhite, Dossey, Kifer, Swafford, Travers, & Cooney, 1987) and *The Mathematics Report Card* (Dossey, Mullis, Lindquist, & Chambers, 1988) have been published. Although these reports and proclamations have focused on the achievement of students, an underlying assumption has been that significant changes need to be made in the teaching of mathematics and in the ways in which teachers learn to teach mathematics. In an effort to address concerns about the status of mathematics education in our nation's schools, the National Council of Teachers of Mathematics (NCTM) has produced two documents, the *Curriculum and Evaluation Standards for School Mathematics Teaching*

(NCTM, 1989) and the *Professional Standards for the Teaching of Mathematics* (NCTM, 1991). Although Weiss, et al. (1990) did not focus on the potential impact of the NCTM *Standards* on mathematics teacher education programs, it seems reasonable to expect that subsequent efforts to train and retrain teachers of mathematics will capture much of the spirit of what these two sets of standards emphasize -- a spirit implicit in Weiss and her colleagues' analysis. There still remain issues of how we can accomplish the vision communicated in the *Standards* through the process of teacher education, however. Within this context, I would like to focus on the relationship between teachers' knowledge of mathematics and reform in the classroom.

8.2 Teachers' Knowledge and Beliefs about Mathematics

It is difficult to imagine a reasonable argument that says a teacher's knowledge of mathematics is unimportant for that teacher's effectiveness. Yet a precise relationship between a teacher's knowledge of mathematics and his or her ability to be an effective teacher remains elusive. Nevertheless, the improvement of teachers' knowledge of mathematics has been the focus of many in-service programs. Indeed, Weiss, et al. (1990) conclude that these programs are quite effective in enhancing teachers' knowledge of mathematics. No doubt such programs are quite important, given that there is a growing literature indicating that elementary school teachers, in particular, are lacking a fundamental understanding of mathematics. For example, Wheeler and Feghali (1983) found that pre-service elementary school teachers have an inadequate concept of zero, given that approximately 75 percent of them did not respond correctly to the question, "What is 0 divided by 0?" Graeber, Tirosh, and Glover (1986) found that pre-service elementary school teachers have difficulty selecting an appropriate operation for solving arithmetic story problems. Fisher (1988) found that many teachers do not understand proportions and direct and inverse variations. Mayberry (1983) found that pre-service elementary school teachers do not have a level of geometric sophistication supportive of their understanding geometry from an axiomatic perspective. Cooney (1990) found that pre-service middle school teachers correctly answered only about 50 percent of items considered representative of the middle school curriculum. Still, there is a paucity of information about how these "inadequacies" actually affect the teaching of mathematics.

At the secondary school level, there is virtually no research on teachers' knowledge of mathematics beyond the coarse method of defining mathematical knowledge in terms of courses taken at the collegiate level. The relationship between knowledge of mathematics so defined and student achievement is generally not statistically, let alone educationally, significant (Begle, 1968; Eisenberg, 1977). From a different perspective, Wilson (1991) found that the four pre-service secondary school mathematics teachers whom he studied lacked an understanding of mathematical functions that would support the breadth of mathematical outcomes envisioned in the NCTM *Standards*.

There is not sufficient evidence to establish definitive conclusions about the relationship between teachers' knowledge of mathematics, their ability to teach mathematics, and student outcomes. The evidence does suggest, however, that the study of university level mathematics alone -- at least as presently constituted -- is not sufficient to ensure that teachers will understand school mathematics deeply enough to realize reform in the teaching of mathematics.

Despite inconclusive evidence regarding the relationship between teachers' knowledge of mathematics and their effectiveness in teaching, the rationale that a knowledge of mathematics is critical to a teacher's effectiveness has hardly been shaken. Nor should it be. Rather the problem lies in how one defines mathematical knowledge and how one defines the effectiveness of mathematics instruction. Rarely do studies involving in-service teachers examine the teacher's knowledge from a perspective that is consistent with the breadth and depth of mathematical interpretations currently emphasized in the reform movement. Yet if we want teachers to develop mathematical communities within their classrooms — communities in which dialogues involving significant mathematics are commonplace — it follows that teachers must have the flexibility to deal with a wide range of mathematical interpretations and outcomes.

The process of increasing teachers' knowledge of mathematics is more complex than it might first appear to be. No doubt the NSF institutes of the 1960s increased teachers' knowledge of mathematics. Weiss, et al.'s (1990) analysis confirms this increase. Missing, however, is a consideration of the context in which mathematics is learned. Steffe provides the following analysis with respect to the way teachers acquire and think of mathematics and how they define their roles as teachers of mathematics:

> As a precollege mathematics teacher, I intended to play the role of a mediator between my students and mathematics and to reveal mathematics to them as a meaningful set of relationships that would have relevance to them as they organized their experiences and their self-understanding deepened. The students, however, were to learn mathematics as it is, not as they might make it to be. So, at the time, understanding the mathematics of my students and how it might be useful to them was not part of what I took to be my responsibility as a

> mathematics teacher. I now take a different view of that responsibility (1990, p. 42-43).

Steffe maintains that the issue of the usefulness and applicability of mathematics becomes moot when the teaching of mathematics is seen as enabling students "to learn mathematics in such a way that it helps them organize their experiential world" (1990, p. 51). The development of this perspective has as much to do with *how* teachers teach mathematics as it does with *what* mathematics they teach (Cooney, 1988).

The shift of which Steffe speaks is based on the notion that one's conception of mathematics and one's means of teaching mathematics are mirror reflections of each other. The significance of this perspective lies in the implicit message that is sent to teachers when they acquire mathematical knowledge through a transmission mode of instruction: Make your lectures clear and logical. I recall a recent interview with a mathematician regarding the effect he would like to have on students attending his lectures. He wanted his students to see mathematics come alive — a goal he thought could be achieved through carefully planned and clear lectures. Apart from the obvious inconsistency that underlies breathing life into a perceived dead subject through a passive medium, we have an inherent interference between what is to be learned and how it is to be learned. The cliché that "teachers teach as they were taught" is legendary. It behooves teacher education programs to be as concerned about helping teachers reconceptualize their conception of mathematics and how they can teach it as they are about helping them acquire a larger set of "mores."

There is considerable evidence (supported by common sense) that life in the classroom is a sea of complexity (Lortie, 1975). Teachers attend to many considerations, some of which are sociologically oriented (Bauersfeld, 1980; Bishop, 1985; Floden and Clark, 1988). But much of this complexity is lost in the classroom dialogues about mathematics, as mathematics is often presented as a cut-and-dried subject (Kesler, 1985; McGalliard, 1983).

There is also evidence that a dualistic perspective (Perry, 1970) is rooted in teachers' experiences long before they encounter formal training in mathematics education (Helms, 1989; Owens, 1987; Wilson, 1991). While these beliefs continue to be modified during teachers' professional lives, they seem not to change dramatically without significant intervention (Ball, 1988; Bush, 1983). From a limited perspective, the teaching and the learning of mathematics is not considered problematic. Rather, the issue is to provide students with information in the clearest way possible. The teacher's job, then, is to be clear and effective in an absolute sense;

the role of the student is to absorb that knowledge. Obscured is the context in which teaching and learning take place and the importance of teaching mathematics from the perspective that students' conceptions matter.

I recall an evaluation I conducted with an elementary school a few years ago. In every class I observed, teachers and students were doing mathematics — an impressive show in many ways. But I also observed that in only two instances did a teacher pose a question that required a response based on other than immediate recall. Imagine the consequence of students thinking that the study of mathematics is a matter of immediate recall rather than a matter of reasoning, communicating, and problem solving. It is predictable that when children eventually do encounter mathematical situations or problems that cannot be resolved solely by recalling information previously given to them, they will reject either mathematics, their teacher, or worse, their confidence in their ability to do mathematics.

Lappan, Fitzgerald, Phillips, Winter, Lanier, Madsen-Nason, Even, Lee, Smith, and Weinberg (1988) addressed the issue of changing teachers' style of teaching through an extensive in-service program. They found that a two-week summer workshop was sufficient to teach material in the project's units but was not sufficient to enable the teachers to transfer their knowledge to topics not specifically addressed in the units. They concluded that this transfer and integration would require a sustained in-service program of at least two years' duration, in which teachers are provided not only technical assistance in using the project's materials but also intellectual and emotional support as well. The sort of change in teachers' beliefs addressed by Lappan and her colleagues is reflected in the confidence the teachers gained in their understanding of mathematics and in their ability to deal with more open-ended instructional styles.

8.3 Concluding Remarks on Present In-service Programs

While the accumulated knowledge base for mathematics teacher education programs is meager at best, there are findings that deserve attention. First and foremost among these is that teaching and teacher education are complex enterprises, one influencing the other in uncertain ways. This complexity is becoming increasingly common as more and more in-service programs are providing contexts for teachers to become reflective practitioners and for creating protracted and continual contact with the supporting program. It is not that the institutes of the 1960s were so wrong-headed, but rather that they missed an essential cog in the wheel of reform. Preoccupation with the mathematics to be learned, as was the case in the 1960s, denies the recognition of the pedagogical implications for how mathematics is learned. No longer can we assume that the substance of the message overpowers the medium by which the message is delivered. Teachers do teach as they were taught.

This realization lays bare significant and different challenges for mathematics teacher education programs. It complicates the issue of teacher education because it necessitates not only the examination of what is to be delivered but also how it is to be delivered. In the section below, I provide a possible foundation for addressing these challenges.

A Developing Consensus about the Teaching of Mathematics

> *The world of technology hit me full in the face as I began to take mathematics education courses. I had grudgingly begun to allow my students limited use of calculators and had ignored the computer except for word processing. I quickly learned that the use of technology should revolutionize the high school curriculum. It was very threatening to learn that most of what I had been teaching students to do could be accomplished faster and better with computers and calculators. I purchased a graphing calculator and quickly became intrigued with its teaching possibilities. . . .*
>
> *At first I resisted the idea that I needed to rethink the emphasis of the high school curriculum. My first reading of the Standards was not fun because so much sounded foreign to me. The ideas looked revolutionary to me and I was suspicious of their worth. I was faced with the uncertainty of thinking about different ways of teaching mathematics.*
>
> *Sue Bingaman*

There are two distinct, interrelated forces that are shaping reform in mathematics education: technology and an emerging new paradigm for the teaching of mathematics. It is unlikely that the world of technology will be relegated to the closet, as has been the case with so many previous "technological" advances in education. As suggested by Robert Davis (1967) many years ago, computers and calculators can do much of what was regarded as commonplace in the curriculum only a decade ago.

Technology has the potential to profoundly impact the teaching of school mathematics. It forces us to reconsider the nature of mathematics, mathematical proof, and what it means to do mathematics. These reconsiderations open up new vistas for teaching mathematics and for defining what it is that we want our students to learn about mathematics. Technology also provides a context for visualizing mathematics that might otherwise not be possible. For example, the range of real-world problems accessible to students because of technology is considerably broader than was the case several decades ago. All of these factors have significant implications for designing mathematics teacher education programs. But before we consider these implications, let us examine the developing consensus regarding the teaching of mathematics.

8.3.1 The Building of a Consensus for Reform

A factor contributing to the likely infusion of technology into the everyday classroom is that its availability coincides with an emerging conception of mathematics as an exploratory science (Davis & Hersh, 1981). While this notion of mathematics is hardly new, technology provides a vehicle and a context that can allow change to be visualized and realized at an accelerated rate. The *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989) and the companion volume *The Professional Standards for Teaching Mathematics* (National Council of Teachers of Mathematics, 1991) have provided the basis for an unparalleled excitement and energy in mathematics education. The Mathematical Association of America is producing "standards" for the teaching of collegiate mathematics that parallel the NCTM Standards. What is the premise of this movement, and what is its likely impact on the field?

While the impetus for change is manyfold, almost everyone agrees that something is wrong with the way our children are being educated mathematically. Poor test scores is usually the point on which the public dwells. Achievement, or lack thereof, is the result of many conditions, not the least of which is that an increasing number of children are bringing devastating societal problems with them through the school doors. But societal ills are not the only culprit. The title of the landmark study *The Underachieving Curriculum* (McKnight, et al., 1987), which details both student achievement and school mathematics curricula in the United States, was not chosen capriciously. It reflects the unmistakable conclusion that the eighth grade curriculum in our schools, with its overemphasis on arithmetic and computation, is decidedly outdated. In contrast, countries such as France and Japan have eighth grade curricula that focus heavily on geometry and algebra, respectively. The fact that much of the curricula in the United States is cyclical in nature, with a minimum of new topics being introduced in the elementary schools (Flanders, 1987), is itself "fixable." Changing the curriculum is not necessarily limited because of societal problems -- although it would be foolish to think that how one defines appropriate mathematics for students is independent of societal concerns (see, for example, Donovan, 1990). The NCTM *Standards* represents one attempt to deal with the curricular issue.

It would be an oversimplification, however, to think that the curricular issue is one of substituting a piece of "modern" curriculum for a piece of "outdated" curriculum. The call for an increased emphasis on problem solving has been made for decades -- witness the *Agenda for Action* (NCTM, 1980). The Standards take this one step further by emphasizing communication and reasoning. That is, the *processes* of doing mathematics must accompany the changes in the *topics* that constitute the mathematics curriculum. It is on this point that curricular issues interface with instructional issues. How does one teach mathematics that encourages students to communicate and reason in addition to solving real problems? A partial solution is addressed in the *Professional Standards for Teaching Mathematics* (NCTM, 1991) although certainly any particular set of standards or proclamations can only form a basis for discussion and not a blueprint for reform itself.

These calls for reform are not just from ivory tower inhabitants. The view of mathematics and its teaching that emphasizes process as well as content is consistent with the following statement:

> We believe . . . that the most effective way of learning skills is "in context," placing learning objectives within a real environment rather than insisting that students first learn in the abstract what they will be expected to apply (U.S. Department of Labor, 1991, p. 4-5).

If reform were limited to curricular changes, the problem would be greatly simplified, and its resolution by an agency such as the National Science Foundation would be relatively straightforward: Fund projects that develop new and innovative curricula. That was essentially the model used in the 1960s with the development of the School Mathematics Study Group, along with institutes for teachers to upgrade their knowledge of mathematics. While curricular changes may be a necessary condition for reform, they surely are not sufficient. In essence, change is a matter of people, not paper and pencil. Hence, simplistic solutions such as changing the curriculum miss the point that is central to the current call for reform, namely, that the *teaching* of mathematics should be changed. For otherwise one set of memorized procedures is substituted for another.

A reasonable question to ask is whether this movement to a more student-centered classroom will become a historic relic, as have its predecessors. The answer may well be, "Yes," although the current movement for reform is broader based in terms of its participants and is better grounded in terms of its epistemology. While the charge in the 1960s was to increase a specialized type of individual — e.g., engineers, mathematicians, and scientists — the current charge is more egalitarian in purpose: Produce a numerate society so that all of our citizens can live a successful life in an increasingly technological society. The reform movement of the 1990s is not only more comprehensive than that of the 1960s, it is also significantly more challenging. The need and call for reform involves a larger segment of the population than was previously the case. It follows that programs to address this challenge must themselves be more comprehensive in scope and design.

8.3.2 In Search of an Epistemology

Previous reforms in mathematics education have had a variety of epistemological bases. In the 1960s reductionism abounded, as most research programs were behavioristic in nature. It is not clear just how this affected the new math era of the 1960s except to say that that movement had no real epistemological foundation other than the realism that was well-ingrained in the logical structure of mathematics. Simply put, the notion was put forth and largely accepted that if one understood the logic of doing mathematics, one could apply that logic to life in general. In many ways this reform was dominated by the national agenda of developing mathematical talent. As an outgrowth of this agenda, the point was made that our society was becoming more mobile and that the kind of workplace projected for the students was speculative at best. It was unclear, for example, just what the mathematical needs of the students would be, given the changing nature of society. The perceived remedy emphasized the abstract and logical nature of mathematics -- something that would stand the test of time.

Research associated with this reform movement was scarce, but what there was consisted primarily of correlating variables of teachers' knowledge of mathematics (defined in terms of courses taken) or various types of teaching behaviors with student achievement through carefully controlled process-product studies. Whether the idea was bankrupt or inappropriately applied matters little. Its influence on mathematics teacher education was meager.

In the 1970s, with the emphasis on basics and competency-based teacher education programs, we again saw reductionism at work as carefully defined behavioral objectives atomized outcomes in mathematics and mathematics education. The emphasis was on attainment of the objectives. The impact that this reductionistic orientation had on mathematics education was far from meager. Testing became the Zeitgeist of education under the notion of accountability. In many instances teacher education programs were reduced to a set of competencies to be acquired under the assumption that such competencies, disparate as they might be, would provide the context for developing a strong teaching force. The remnants of a competency-based teacher education program and its basic skills orientation live on in many ways, although it is now largely recognized as an unproductive, if not harmful, approach to mathematics education.

In the 1980s, calls for reform began to emerge, fueled by studies such as the National Assessment of Educational Progress and the Second International Mathematics Study. Although it would be an exaggeration to say that these calls for reform were driven by a dissatisfaction with the reductionistic epistemologies of the previous decades, it is nevertheless an interesting coincidence that these two events paralleled one another. Current reformers call for a shift away from mathematics seen as the execution of predetermined algorithms in predictable contexts and toward a view of mathematics as a set of structures and a language by which one reasons and communicates quantitatively. The underlying epistemology of this reform has many nuances, but the term most frequently used to capture the notion of learning mathematics as a language of communication, a perspective that emphasizes another person's meaning-making process, is *constructivism*. It is not the intent here to deal with all of the trappings of this epistemology but rather to point out that, in this epistemology, the context in which an individual works is central to understanding the meanings that a person holds. It follows that the teaching of mathematics is then a matter of creating circumstances in which students are encouraged to construct meaning. The following, dialogue reported by Yackel, Cobb, Wood, Wheatley, and Merkel illustrates this emphasis on communication and meaning making:

> When children are presented with tasks and encouraged to solve them in ways that make sense to them rather than follow procedures that have been presented by the teacher, they develop a variety of solution methods. Early in the school year, children offered the following solution methods for solving
>
> $$9 + 11 = \_\_\_\_ .$$

Brenda: *9 and 9 is 18, plus 2 is 20.*
Adam: *7 and 7 is 14, so 8 and 8 is 16, 9 and 9 would be 18 so 9 + 11 must equal 20.*
Chris: *11 and 11 equals 22, 10 and 11 equals 21, 9 and 11 equals 20.*
June: *11 and 9 more -- 12, 13, ...,18,19,20.*

> As these examples illustrate, in a conducive setting children use what they already know to develop personally meaningful solutions. Their solutions reflect differences in the current knowledge they bring to the task (1990, p. 13).

Given this shift in epistemological perspective, the energy that the *Standards* and other reform-minded documents have fostered, and the availability of technology to support reform, the conditions are in place for realizing significant change in the teaching and learning of mathematics.

Despite the potential for change, however, reform at the classroom level is in its infancy, at best. This seems to be particularly so with respect to how students' understanding of mathematics is assessed. Cooney (1992) conducted a survey on secondary mathematics teachers' evaluation practices in which 201 teachers from grades 7-12 completed a questionnaire that focused on their general evaluation practices. A subsequent questionnaire aimed at obtaining the teachers' reactions to five nontraditional assessment items was completed by 102 teachers of these teachers. Subsequently, 18 of these teachers were interviewed.

The first questionnaire contained the following item:

> Write or draw a typical problem that you gave students that you believe tests a deep and thorough understanding of the topic.

Fifty-seven percent of the teachers responded by generating items that were basically computational in nature. The following items were typical of these responses:

(a) $4\ 1/3 + 2\ 2/5$

(b) *Solve for x:* $6x - 2(x + 3) = x - 10$

(c) *How much carpet would it take to cover a floor that is 12.5 ft. by 16.2 ft.?*

Many teachers seemed to conflate the notion of difficulty with assessing a deep and thorough understanding of mathematics. This conflation is consistent with descriptions the teachers provided during the interviews, viz., that the teaching and learning of mathematics is basically a step-by-step process. Hence the difficulty level is essentially determined by the number of steps needed to solve a problem -- clearly a reductionistic perspective. Such a perspective almost certainly excludes outcomes involving significant experiences in problem solving, communication, or reasoning.

The position that not much will change in the teaching and learning of mathematics unless assessment is an integral part of the reform process is reflected in the following statement by Crooks:

> Classroom evaluation affects students in many different ways. For instance, it guides their judgment of what is important to learn, affects their motivation and self-perception of competence, structures their approaches to and timing of personal study (e.g., spaced practice), consolidates learning and affects the development of enduring learning strategies and skills. It appears to be one of the most potent forces influencing education. (1988, p. 467)

The survey by Cooney (1992) suggests that assessment should be given considerable attention in in-service programs if progress toward reform is to become a reality. Yet, assessment is rarely mentioned in various descriptions of in-service programs.

In some sense the crux of the matter is what we consider mathematics to be. Given that other research (see Brown, Cooney, & Jones, 1990) tends to support the notion that many teachers either hold or communicate a limited perspective of mathematics, it seems clear that teacher education must deal with not only the content teachers are learning but also the means by which they learn that content. A limited conception of mathematics, instruction, and its flip side, assessment, mathematics education will necessarily fail to promote the kinds of outcomes now being called for. Thus it is imperative that in-service programs pay particular attention to the contexts in which mathematics is learned *and* in the way it is assessed.

8.4 The Contribution of Research to Developing In-service Programs

While the creation of a viable teacher education program is unlikely to be based solely on research, research can nevertheless provide directions for designing teacher education programs. Silver (1990) discusses three contributions research can make to educational practice, including teacher education: (1) research findings, which can serve as guiding principles for educational practice, (2) methods or tasks used in research, and (3) theoretical constructs and perspectives derived from research. Based on Romberg and Carpenter's conclusion that "'scientific' studies related to the teaching of mathematics have failed to provide teachers with a list of tested behaviors that will make them competent teachers and ensure that their students will learn" (1986, p. 865), the first type of contribution identified by Silver is not likely to be a significant factor in shaping most teacher education programs. Brown, Cooney, and Jones (1990) reached a similar conclusion.

Perhaps as a counterpoint, however, a research program at the University of Wisconsin called *Cognitively Guided Instruction* (CGI) has developed an extensive body of knowledge on first-grade students' higher-order thinking skills, which in turn has provided a basis for an in-service teacher education program (Peterson, 1988). The basis for the in-service program is the research findings from the project, which in turn are used to increase teachers' knowledge and sensitivity of how to promote higher-order achievement among first-graders. Peterson provides the following description of the teacher education component of CGI:

> In addition, CGI teachers were *not* trained in specific techniques for altering their classrooms and curricula. Thus, in applying a CGI approach to "educating" the teachers and working with them as "thoughtful professionals," who construct their own knowledge and understanding, we remained consistent with our theoretical framework drawn from cognitive science. However, the result will undoubtedly be large variations in the extent and degree to which CGI teachers change their curricula and teaching to incorporate CGI principles. Indeed, our preliminary observation of CGI teachers' classroom implementations suggested that this is the case (1988, p. 23).

This finding is similar to that of Good, Grouws, and Ebmeier (1983), who found that teachers do change their teaching when provided appropriate research findings, but their application of that knowledge is far from systematic or certain. Indeed, these authors raised the question as to why some teachers "took" the training and others did not. This in turn raises the question of how in-service programs can get "connected" to what teachers can meaningfully tolerate in their classrooms.

The success of CGI highlights the role that research can play in structuring a teacher education program, although the question of just how that knowledge has an impact on teachers is worthy of study. One of the few areas of mathematics education that has a well-established knowledge base is young children's knowledge of addition and subtraction. While considerable research is being conducted on children's understanding of fractions and rational numbers, and some research is being conducted on students' understanding of algebra and geometry, there is not a sufficient knowledge base on which to develop a teacher education program. Even if extensive knowledge bases about students' understanding of mathematics existed, we would still be lacking in our knowledge about how teachers learn to teach those topics. The issue of "learning to teach" is fertile ground for research in mathematics teacher education.

I will not explore the notion of how various research tasks can be used in teacher education programs, although clearly there are implications. Consider, for example, the repertoire grid technique (Kelly, 1955) and the use of this technique in categorizing various problems, students' responses, or whatever. I consider below a theoretical perspective that can provide significant direction for in-service programs — namely, constructivism.

8.4.1 The Implications of Constructivism for In-service Programs

The notion of constructivism invites many interpretations and has several different varieties, e.g., social constructivism, radical constructivism, and social connectionism. Basic to all, however, is the notion that individuals construct meanings based on their experiential world and that any attempt to understand another's world view must account for the context in which those meanings were constructed. Bauersfeld (1988) speaks of this as *fundamental relativism*. Von Glasersfeld (1987) talks about the viability of one person interpreting the actions of another or the "fit" that one creates to understand another. From this perspective, the task of the researcher is to explain a child's interpretation by seeing if the explanation "fits" what the child seems to be saying in a variety of circumstances. Thus mathematical knowledge is seen as being unique to an individual. Such a perspective invites us to change the oft asked question, "How is Mary doing in mathematics?" to "How is mathematics doing in Mary?"

According to von Glasersfeld (1989), the following two principles underlie the radical constructivist perspective:

1. Knowledge is not passively received but actively built up by the cognizing agent.
2. The function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality.

It would not be difficult to find mathematics educators who would ascribe to the first principle, identified by von Glasersfeld as the principle of *trivial constructivism*. Indeed, I suspect that most educational psychologists could make the case that their research is about building knowledge structures within the learner. It is the second principle that causes the difficulty in interpreting constructivism, particularly as it relates to teacher education. From the "reality" of the teacher educator, a potential conflict is seen between realizing the NCTM *Standards* and teachers' limited conception of mathematics or the teaching of mathematics. But what teacher educators must realize is that from the teachers' "reality" no such conflict may exist. Thus, teacher education runs the risk of providing answers for which there were no questions.

Also, there is the influence that students bring to the classroom. Borasi (1990) suggests that students hold a limited conception of mathematics (never mind how they came about this limited conception) which significantly influences instruction. This position is supported by findings from the Second International Mathematics Study. In responding to these expectations and in trying to define their own role as mathematics teachers, teachers seldom relish uncertainty in the classroom that necessarily results from a problem-solving orientation toward the teaching of mathematics. Thus life in the classroom becomes marked by predictability. The field is replete with foiled attempts to innovate and overcome this sterile predictability. As an example, consider the following analysis by Shulman regarding attempts to increase teachers' wait time:

> Thus, one possibility is that teachers are being invited to employ pedagogical devices which not only yield better pupil cognitive performance, but also a higher frequency of classroom management problems, and that is a trade they are not prepared to make. Another possibility is that as pupil responses increase in their cognitive complexity we also observe an increase in the number and potency of critical moments. The higher quality cognitive response is intrinsically less predictable than that of lower quality. Hence, increasing time for responding almost guarantees that the teacher's role will become more ambiguous and classroom events will become less predictable and under less direct teacher control. Thus teachers may return to shorter wait-times because the multiplication of critical moments and the reduction in their ability to predict and control classroom events exceeds what they have learned to tolerate (1978, p. 18).

While Shulman's comment was made over a decade ago and pertains to a specific pedagogical skill, it seems as appropriate in today's classroom as in yesterday's classroom — perhaps even more so.

While teacher educators are sometimes quick to criticize teachers for failing to consider the mathematical world of the child, as a profession we sometimes fail to consider the teacher's world as we design in-service teacher education programs. The key concept here is adaptation, which implies that the cognizing agent (the teacher) is aware of the constraints causing the problem and can assess the potential value of alternative actions. From the constructivist perspective, teacher education concerns helping teachers understand their environment and enabling them to develop strategies for dealing with it. But to do this, the teacher educator must honor the teacher's reality as best as it can be understood. The metaphor of therapy is an appropriate orientation in the sense that therapy strives to analyze, reflect, and provide an alternative courses of action rather than reach a definitive conclusion. It is not that teacher educators should become therapists; rather the metaphor of therapy may suggest a direction for teacher education, as Brown (1982) suggests. The essence of the matter is in coming to grips with creating contexts for teachers to consider what it is that they want to accomplish and what kinds of classroom environments they are willing to create.

8.4.2 Concluding Remarks about the Teaching of Mathematics

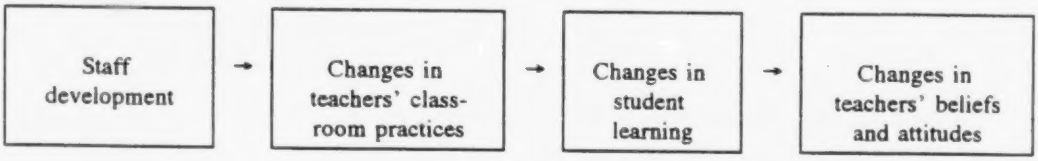
Considerable consensus exists in the profession today about the idealized mathematics classroom, as defined by the NCTM *Standards*. What is not so clear is how the profession can move toward realizing this vision. On the one hand, the evidence suggests that teachers have "deficiencies" in that they lack knowledge, confidence, the ability to generate instructional alternatives, and — perhaps most importantly — an enlightened view of mathematics. On the other hand, to view the problem as a "deficiency" is to suggest a strategy of *giving* teachers' information to remove the "deficiency." Indeed, this is often the language that teachers use to describe their students -- a language that teacher educators are quick to criticize despite the fact that that language often underlies the design of many in-service programs.

The notion of constructivism can be helpful in addressing the problem. Here the emphasis is on adaptation, which implies that context, reflection, and the generation of alternatives within that context are central to the process of change. Accordingly, in-service programs should focus on helping teachers identify their constraints, the knowledge that might be appropriate for addressing the problem, and the strategies for dealing with the problem. This is not to deny what Scheffler (1965) calls an individual's *motivational blindedness* — that is, the sense in which each of us blocks certain aspects of our human condition from our mind, perhaps as a defensive mechanism. The struggle, then, lies in enabling the teacher to come to grips not only with his or her perceived difficulties, but also with those perceived by others and subsequently to provide a context in which they can begin to see ways of overcoming those difficulties.

> *Not until I started teaching again did I realize how changed I had become in a year of exposure to new ideas. Suddenly I was critical of our traditional texts. I moved my students out of straight rows, I encouraged the use of calculators for all purposes, and I started involving students in computer explorations. Increasingly, I found myself asking more questions and providing fewer answers.*
>
> *But the new ideas I brought back met with resistance at every turn. The other mathematics teachers did not welcome the call to change. Administrators worried that I was onto a fad and questioned the adoption of new methods and curricula. Students and parents resisted doing anything different from the previously successful programs. I had to learn to back off with my enthusiasm and give others time to think that the new ideas were their own. Promoting change in my school was a real challenge.*
>
> *Sue Bingaman*

For the most part, in-service programs focus on some combination of teachers' knowledge of mathematics and pedagogy. They also try to influence the way that teachers think about mathematics. In-service programs have tended to focus more on the teaching of elementary or middle school mathematics than on the teaching of secondary school mathematics. Although the evidence indicates that elementary school teachers are lacking in their knowledge of mathematics, there is also evidence (see Brown, Cooney, & Jones, 1990) that secondary school mathematics teachers often hold or communicate a limited conception of mathematics as well -- a point rarely emphasized in secondary school in-service programs.

A question then arises as to whether in-service programs should focus on changing beliefs, in the hope that changes in practice will follow, or whether changes in practice will promote changes in beliefs. Guskey (1986) suggests that changes in teachers' beliefs and attitudes *follow* changes in student outcomes which, in turn, follow changes in teacher practice, as suggested in the model below:


Staff development
Changes in teachers' class-room practices
Changes in student learning
Changes in teachers' beliefs and attitudes

Whether this model holds is problematic. Indeed, the question can be raised as to whether beliefs and attitudes in this context matter at all. On the other hand, it can be argued that without impacting on what the teacher believes mathematics is, very little else matters. Hersh expressed this perspective in the following way:

> One's conceptions of what mathematics is affects one's conception of how it should be presented. One's manner of presenting it is an indication of what one believes to be most essential in it . . . . The issue, then, is not, What is the best way to teach? but, What is mathematics really all about? (1986, p. 13)

The lack of definitive evidence about the merits of either approach leaves open the question about the focus of in-service programs. While most in-service programs for elementary school teachers acknowledge and try to deal with both mathematical content and beliefs and attitudes about mathematics, there seems to be little, if any, attention to the beliefs and attitudes of secondary school teachers. Apparently it is assumed that one's technical knowledge of mathematics suffices for teaching mathematics from a broader perspective. This assumption seems to persist despite a growing body of evidence that teachers and students share a rather limited perspective about what it means to do mathematics.

While no single effective method of promoting change in the classroom has been identified, several characteristics of in-service programs deserve attention. In an effort to enhance the professionalism and effectiveness of teachers, the Cleveland site of the Urban Mathematics Collaborative Project addressed four themes: Socialization and Networking, Increased Knowledge of Mathematics Content, Teacher Professionalism, and Teacher Leadership (Webb, Pittelman, Romberg, Pitman, Reilly, & Middleton, 1991). The obvious breadth of this approach is indicative of the complexity that is being increasingly recognized in in-service programs. For example, each site of the Quantitative Understanding: Amplifying Student Achievement and Reasoning (QUASAR) project has developed a comprehensive staff development program that focuses on content, instructional skills (e.g., posing higher order questions), instructional strategies (e.g., cooperative learning, concept attainment through the use of manipulatives), and classroom management (e.g., keeping students on task, effective use of instructional time). The larger and more comprehensive in-service projects, such as the Urban Mathematics Collaborative Project and the QUASAR project, share the following components: collaboration among various professionals, professional involvement over an extended period of time, and creating an exploratory atmosphere similar to that which teachers are encouraged to create with their students.

8.5 The Importance of Collaboration and Partnerships

One of the increasingly recognized phenomena of teaching as a profession is the isolation of the teacher. Collaboration and the forming of partnerships among various professionals is seen as a way of overcoming this isolation. Kloosterman, Barman, Russo, and Gorman (1988) emphasize the importance of treating teachers as professionals and providing contexts in which teachers have repeated opportunities to share and discuss their experiences in teaching mathematics. There is also an effort to bring school board members and administrators into the teacher education process. Kroll (1990) describes a program in which teachers and principals worked together to achieve common goals. While the principals had a decidedly practical orientation, the support of the school principal and other administrative staff was considered critical to the change process. Popkewitz and Myrdal (1991) also emphasize the importance of teacher professionalism to reform in the classroom.

Although professionalism has many meanings, at the core is the notion that teachers have some sense of control over their professional lives. Romberg (1988) identifies various recommendations for promoting professionalism among teachers, including an emphasis on collaboration and communication with other teachers and developing a framework for rigorous self-regulation — a form of communication in itself. It seems clear that the level of professionalism suggested by Romberg requires that teachers be supported for their involvement in various professional activities, taking "pedagogical" risks in trying new ideas, setting their own goals, and having the opportunity to share their experiences in teaching with others. The evidence strongly suggests the importance of teachers becoming actively involved in collaborative efforts with peers and administrators. While there are various ways to achieve this (e.g., peer coaching), the breaking-down of the isolation of the teacher was described as a significant outcome for many in-service programs. Concomitantly, teachers must be provided the time to participate in these activities.

Essential to the emerging notion of professionalism is the notion of ownership. Smith (1992) emphasizes the importance of ownership in the QUASAR project in terms of teachers' active involvement in the development, implementation, and modification of new programs. Indeed, projects reviewed for this chapter consistently emphasized the importance of teachers having a sense of ownership for the in-service program in which they participated. It was through this sense of ownership that the isolation of the teacher was overcome or at least significantly reduced.

8.5.1 The Importance of Sustained Contact in In-service Programs

The recognition that change in education is a slow and cumbersome process has significant implications for in-service programs. Because of the complexity inherent in change, it takes time and considerable support for teachers to incorporate new ways of teaching and the use of technology into their teaching. This mandates that effective in-service programs take place over an extended period of time, with the teacher being embedded in a variety of professional activities. It also suggests the importance of in-service teacher education programs, as it is rarely the case that pre-service teachers can engender the kind of teaching called for in proclamations such as the NCTM *Standards*. While strong pre-service programs are an absolute must if we are to produce the kinds of teachers that can realize the *Standards*, it is the in-service programs that provide the nurturing to support continuing professional growth.

In the QUASAR project, teachers are engaged in professional activities that cross several academic years. At one school site, the program consists of an initial workshop, monthly follow-up sessions, course work from a local college, a sequence of planned meetings among participants, and weekly classroom visits by resource partners. Release time for the teachers was provided (Smith, 1992). While such a comprehensive approach is expensive, it honors the necessity for continuing, sustained contact among teachers and resource personnel in order to effect change.

While the single-shot workshop may serve a useful purpose in leading to other kinds of activities, the evidence is overwhelming that significant change requires sustained contact. Such contact fosters the importance of professionalism, as teachers have a context that nurtures their becoming reflective practitioners.

8.5.2 The Importance of Establishing Exploratory Environments

Along with collaboration and continuity is the creation of contexts in which teachers are encouraged to become "experimenters." In a sense, good teaching models the scientific spirit, in that it requires conjecturing, creating and testing hypotheses about teaching and learning, and reformulating and testing new hypotheses. It involves risk taking, exploration, and a genuine interest in pushing the bounds of traditional practice. In the *Professional Standards* (NCTM, 1991), one focus is on the importance of teachers creating learning environments that encourage exploration, the development of mathematical skill and proficiency, and the taking of intellectual risks by raising questions and formulating conjectures. What needs to be recognized is the symmetry between the environment that teachers are asked to create and the environment that teacher educators should create to engender this spirit of inquiry.

Just as we hope that teachers will develop the capacity to take into consideration what the student knows and believes about mathematics, the teacher educator has the responsibility to take into consideration what the teacher knows and believes about the teaching of mathematics. Certainly there are technical aspects to the teaching of mathematics (e.g., classroom management and knowing the content), just as there are certain basics to knowing mathematics (e.g., basic facts, certain formulas). But when the spirit of either enterprise becomes dominated by a "fix the deficiency" mentality, learning becomes an activity more marked by accumulation than reflection. The honoring of this broader perspective suggests the need for an environment in which teachers can see themselves as being engaged in professional activities that model the kind of environment they should be creating for their students.

8.5.3 Blurring the Distinction between Content and Pedagogy

In almost all of the descriptions of in-service programs uncovered in this review, attention is given to various means of involving teachers in activities that address the way mathematics is taught. There is scant attention, however, to the interfacing of content and pedagogy. This is not to say that the content is treated as a static entity. Yet it is striking that pedagogical concerns seem to be driven by forces outside the field of mathematics per se. Consider, for example, the emphasis on communication, group dynamics, and cooperative learning that is the focus of many in-service programs.

Good as these programs are, they potentially mask the power that can be derived from seeing pedagogy as emanating from mathematics itself. At the conceptual level, there is, for example, the notion that fractions can be represented by the number line, regions, decimals, ratios, measurement, ordered pairs, and the like. The notion of multiple embodiments is hardly a newcomer to the field of mathematics education. What is new, however, is technology and the means by which it allows us to access even the most elementary procedures from different perspectives. Consider the task of solving linear equations in one variable, a task faced by every algebra student. Students almost universally solve the equation $x - 4 = 2x + 1$ using field axioms or shortcuts based on those axioms. But imagine what it means to envision a solution in which each side of the equation is thought of as a separate function. We could envision the graphs $y = x - 4$ and $y = 2x + 1$ and where they might intersect. Alternately, a spreadsheet could be used to compare values for the functions $f(x) = x - 4$ and $f(x) = 2x + 1$ and where the function value is the same. While such approaches are certainly less efficient than solving the equation using the usual mechanistic approach, what is gained is the flexibility in thinking about what equations represent and how they can be conceptualized from a functional perspective. Consider the value in learning such a perspective when solving equations of the form $2^x = 145$ or $x \sin x = 100$. The pedagogy that stems from this perspective has its roots in mathematics, supported by the use of technology.

One of the values of the *Standards* is the attention and recognition given to the various processes of doing mathematics. These processes are reflected in many in-service programs, problem solving being the most notable. Various in-service projects provide teachers with a wide array of problems to use with their students and videotapes that model the teaching of problem solving. In terms of communication, Azzolino (1990) discusses how mathematics can be taught through various writing activities. What must also be valued is the connections not only of mathematics to real world phenomena, but also the connections within the field of mathematics itself, and the power of these connections to reveal various approaches to the teaching of mathematics. Consider, for example, the history of the development of the function concept as mathematicians struggled to describe physical phenomena. Consider, took the implications of that struggle for helping students see the necessity for studying functions as a means of exploring phenomena of interest to them. Such an orientation has significant and pervasive implications for the way mathematics is taught in the classroom -- not to mention the implications for in-service programs to help teachers teach mathematics from such a perspective.

As mentioned above, there is scant evidence that mathematical knowledge, as defined by courses taken at the pre-service level, is significantly related to teaching mathematics as suggested in proclamations such as the NCTM *Standards*. Yet the first standard in the *Professional Standards for the Teaching of Mathematics* begins by stating that "the teacher of mathematics should pose tasks that are based on sound and significant mathematics" (NCTM, 1991, p. 25). "Sound and significant" means more than being correct. It means understanding relationships, having the flexibility to see or use mathematical concepts or procedures from multiple perspectives, and thinking of mathematics as a means of communication. It is from such a rich conception that mathematics becomes the study and exploration of patterns rather than an exercise in imitation. It is in this sense that the boundary line between content and pedagogy becomes blurred and, instead, they come to be recognized as intertwined.

8.6 Conclusion

There is evidence that the mathematics conveyed in the classroom tends to be static and lacks the richness of mathematics conveyed in the *Standards*. This orientation comes in part from the way teachers communicate mathematics, from the expectations of the students in what they consider mathematics to be (and how it should be taught), and from the way mathematical learning is assessed. In-service programs can break this cycle by promoting collaboration and professional development over an extended period of time. Indeed, it is highly unlikely that this cycle can ever be broken without significant in-service programs.

The recognition of impediments to successful teaching is a first step toward realizing reform. Sometimes impediments are external to the classroom -- problems that people bring with them when they enter the school building or the constraints that are placed on teachers by parents or administrators -- as well meaning as they may be. But sometimes the impediments are the products of the classroom itself -- the teachers' and students' conceptions about what life in the classroom is all about. Bauersfeld provides the following analysis of how change in the teaching of mathematics can occur:

> But, if we form our cognition and behavior about teaching through social situations, then we can also change this formed cognition and behavior through social situations. We learn to behave in social settings only through the reflected participation and action in social settings. Similarly, a teacher will learn to teach or to change his teaching pattern only through [reflective] teaching. Yet, this is not the ruling model of present pre-service teacher training (1980, P. 38).

Although his remarks focused on pre-service teacher education, they apply to in-service programs as well. It is not just the technical aspects of in-service programs -- what gets emphasized and what does not -- that make a difference, it is also the contexts that embody those technical aspects. The recognition and overcoming of impediments to reform require that teachers work in a social context in collaboration with others over an extended period of time. If there is one single message that is revealed from a synthesis of the literature on teacher education, it is that reform is not a matter of paper or pencil or a matter of lists. It is, rather, a matter of people and how they can come to grips with what they think constitutes their role as teachers of mathematics.

Epilogue

Gradually change has happened at my school and we are now moving in the direction that I had so resisted for much of my study. I see myself as now more open to change and more tuned to reading the professional literature for further new ideas. I am presently working to begin a sabbatical leave policy at my school so that others may benefit from a mid-career shakeup, as I did. In our era of rapidly accumulating new possibilities, no one should teach a lifetime using the same assumptions with which he or she began. I am convinced that full-time study in a challenging program is not a luxury, but a necessity for enabling good teachers to become even better.

Sue Bingaman

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PART FOUR: PERSPECTIVES

9 OBSERVATIONS AND CONSIDERATIONS

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9.1 Introduction

Science and mathematics education is in a period of transition. As the preceding chapters make clear, this reform process has important implications for instructional practices and for the in-service education of teachers in the United States. This volume was conceived as a way to communicate with the various constituencies concerned about the quality of science and mathematics education. The book offers, we hope, information and insights that should be valuable to classroom teachers, educational administrators, colleges and universities that train teachers, government policy makers, and funding agencies. This final chapter summarizes key issues and themes highlighted in the preceding ones and discusses the implications of these topics for various groups concerned with maintaining a vital work force of science and mathematics teachers in the nation's schools.

9.2 Teacher Enhancement: A Compelling Priority

In an era of rapid change, it goes without saying that teachers need opportunities to update their knowledge and develop new professional skills. The figures Weiss reports, however, make the case for in-service education of mathematics and science teachers even more compelling. Too few teachers have a background in their teaching field that measures up to the current standards of national mathematics and science professional associations. The vast majority of teachers receive so little in-service education annually it is hard to believe that they are staying abreast of developments in their subject areas.

Teachers encounter a discouraging array of factors that inhibit their professional renewal and, hence, their successful performance. Inappropriate curricula, outdated equipment, and bookkeeping, and administrative duties each decrease the time and energy teachers can invest in their own professional enrichment. Standardized achievement examinations for students that emphasize precise factual information on a broad range of topics likewise constrain teachers.

Fears about poor student performance on national tests inhibit many teachers from exploring interesting new subject areas and teaching techniques and experimenting with them in their classrooms. The evidence that science and mathematics instruction continues to be dominated by "textbook-lecture-recitation" methodology suggests that teacher in-service education in the United States must be expanded and made more effective.

9.3 Common Themes, Critical Issues

One underlying theme pervades all of the chapters in this book on teacher enhancement: Fundamental reform in science and mathematics education is necessary to meet the needs of our diverse and technologically-driven society as it moves into the twenty-first century. Currently a large segment of the American population is functionally illiterate in science and mathematics. The authors reflect the widespread consensus that the goals as well as the methods of science and mathematics education must be dramatically redefined in order to provide a strong foundation in science and mathematics for all of our citizens.

Fortunately, a new conception of how best to teach mathematics and science is emerging as the need to reach out to a larger portion of the population becomes critical. The constructivist view of how knowledge and understanding develop questions the validity of traditional, transmittalist educational practices that see the teacher as a subject-matter expert who transmits large quantities of information to passive students. The constructivist point of view presented in these chapters acknowledges the centrality of the learner to the instructional process. The authors argue that teachers must take into account their students' prior knowledge and understanding before they can move them efficiently to higher levels of achievement in mathematics and science. Rigidly defined curricula that fail to recognize the unique understandings and contexts of the students in a classroom inevitably leave behind those students whose prior experience with mathematics or science is not consistent with the assumptions of the curriculum designers.

The chapters in this volume argue for the elimination of passive, textbook-bound instruction that promotes rote memorization rather than critical thinking and the development of in-depth comprehension. The chapters advocate a "less is more" approach to science and mathematics education. By presenting less factual information more effectively, teachers can help students gain a clearer understanding of scientific and mathematical processes and better apply this knowledge in real-life situations. The effective teacher, as described here, is a learning facilitator, not a mechanistic conveyor of information.

The authors of the chapters in this book share a belief that teachers must be key players in the reform of science and mathematics education. Although many groups must collaborate in order to transform traditional approaches to science and mathematics education, no group is more important to the reform process than teachers. Reforms cannot be implemented without teachers adopting them as their own and breathing life into them in the classroom.

Constructivist assumptions about learning apply to teachers as well as their students. In order for teachers to adopt a significantly new approach to education, they must first develop a clear conception of the problem, alter their understanding of what instruction should entail, and shape new instructional strategies consistent with the constructivist philosophy. The authors explain why convincing traditionally trained teachers to radically modify their approach to teaching mathematics or science is not a simple task. Like students who have worked out a flawed, but comfortable, explanation of why the seasons change, transmittalist educators must be confronted with the discrepancies between widely practiced modes of science and mathematics instruction and the constructivist understanding of how learning actually occurs. In-service teacher enhancement activities are an essential element in this transition process, and they must challenge teachers' unexamined assumptions about how students gain knowledge and understanding, as the first step in converting teachers to the education reform movement now underway.

Convincing science and mathematics teachers of the merits of educational reform is a necessary, but not sufficient, step in the quest for educational improvement, however. Perhaps the most important task of teacher enhancement initiatives is to *empower* teachers to alter their classroom performance in significant ways. In order to put into practice the educational reforms advanced by the authors of this book, teachers need adequate time, resources, ongoing support for professional development, and opportunities to practice new educational strategies.

To support state-of-the-art instruction, in-service education programs must expand teachers' knowledge base. Mestre and Peterson recommend that teacher enhancement programs add to teachers' subject-matter content knowledge. Teachers need to be confident enough in their understanding of content to accept children's alternative views and to envision diverse paths to help each student move to an accurate conception. In addition, Mestre argues that in-service education should acquaint teachers with the constructivist view of learning and the cognitive research literature. Perhaps most important, both Peterson and Mestre believe that in-service education must familiarize teachers with instructional strategies that facilitate the promotion and monitoring of students' conceptual understanding.

Strengthening teachers' professional knowledge base must be supplemented by opportunities to apply the information provided during in-service education. Shavelson and his coauthors suggest that teacher enhancement programs should model or demonstrate the types of instructional strategies they advocate. Naturally, what is demonstrated is closely related to the curriculum employed in enhancement projects. Raizen describes the many different science curricular materials available, as well as the varying approaches to instruction each represents. In mathematics, as described by Romberg, the *Standards* provide strong theoretical guidance, but fewer curricular materials are available.

In addition to modeling, the in-service education programs should provide opportunities for participants to practice what they are learning. Practice serves as a bridge between the new knowledge acquired during in-service education and implementation of that knowledge back home in the classroom. It also serves to reinforce, or strengthen, that which was taught. Too often, unfortunately, the practice phase of teacher enhancement is missing, as teachers sit passively listening to expert professors lecture about new developments in their fields. When this occurs, the chain of events leading to dramatic change in the precollege classroom is broken.

The process of teacher enhancement should never end when the in-service workshop or seminar ends. The Shavelson team convincingly argues that one-shot workshops are ineffective at altering teacher performance. Both follow-up from workshop leaders and support from personnel at the home institution are needed to ensure that teacher enhancement projects achieve their intended effects. Project newsletters, reunions where project participants share how they have applied what they learned in a workshop, and visits to teachers' classrooms by the leaders of in-service education projects are forms of follow-up that can promote the transfer of learning from a workshop or seminar to the classroom setting.

Cooney contends that it takes time to implement effective instructional practice. Teachers need intellectual and emotional support as well as technical assistance, as they break old teaching habits and experiment with alternative approaches to instruction. In some cases, new equipment or updated facilities are necessary to integrate ideas brought home from a teacher enhancement program. Teachers may also need some release time from other duties in order to translate new ideas into concrete instructional practices. Observation and coaching by administrators or peers can help teachers gradually improve their application of new strategies. According to Shavelson and his coauthors, the teacher team is perhaps the most powerful mechanism to support teacher enhancement. A group of colleagues working together to implement innovative concepts in their classrooms can reinforce one another's efforts by creating a reform subculture within a school.

Evaluation should be a critical component of any teacher enhancement initiative, yet it often receives the least amount of thought or effort. The authors of this book make a compelling case for evaluating in-service education programs. Formative (in-process) evaluation is needed to determine whether programs are unfolding as they were intended. Gathering information in the midst of a project is consistent with the constructivist philosophy, because it enables project leaders to tailor in-service activities to the distinctive needs and interests of project participants. Summative (final) evaluation is necessary as well, in order to assess the outcomes of a project. Did it achieve its original goals and objectives? Did unanticipated outcomes occur? Was it worth the time and resources invested? As an integral part of the teacher enhancement cycle, evaluation enables the leaders of in-service education programs to refine their strategies and serve diverse groups of teachers. As Cooney suggests, many in-service education programs are ad hoc operations that lack a theory or research base. Systematic evaluation of the operation and outcomes of teacher enhancement initiatives can help to place these programs on a firmer foundation.

9.4 Implications for Policy and Practice

This book leaves no doubt that the reform of science and mathematics education in this country requires the collaboration of many constituencies and interest groups, both within and outside the education enterprise. Each of the chapters helps to clarify the needed reforms and offers guidance on how teacher enhancement can help to advance the reform process. Specific implications for policy and practice emerge from the chapters. These are presented here as recommendations to the groups best qualified to take action in support of improved science and mathematics education.

9.5 Teachers

First, this book has implications for science and mathematics teachers. Three specific suggestions emerge:

1. Teachers need continuous professional growth in order to keep pace with rapid developments in science and mathematics. In-service education is also necessary to enable teachers to adapt their educational strategies to the increasingly diverse student population they are called upon to serve. Teachers have a professional obligation to seek out opportunities for renewal on a regular basis.

2. Teachers need to become reflective practitioners. As they participate in professional growth activities, they need to apply this new knowledge to their classroom situations. They need to become integrators of old and new knowledge. They need to be problem solvers; to apply their knowledge to the existing situation so as to optimize learning and to keep experimenting and reflecting so that the optimization continues.

3. A "less is more" approach to teaching is necessary to expose students to the interactive, dynamic nature of science and mathematics. By reducing the number of different concepts transmitted in their classes, teachers can concentrate on developing students' comprehension of fundamental concepts. This should take place through the use of experimentation, cooperative learning, conceptual discussion, and other modes of active intellectual involvement that facilitate information processing.

9.6 Teacher Enhancement Project Leaders

The authors of this book had leaders of teacher enhancement programs, staff development specialists, and others with in-service education responsibilities specifically in mind as they prepared their chapters. Recommendations for this audience include the following:

1. Have an explicit and consistent theoretical framework for the project that guides all of the activities. This would include clear goals and objectives for the project and what outcomes are expected.

2. Assess teachers' assumptions and beliefs concerning students and science and mathematics instruction at the beginning of in-service education projects. Teacher enhancement activities should be based on the knowledge and beliefs teachers bring to a workshop or seminar. Failure to understand teachers' "views of the world" will limit the effectiveness of any in-service education activity.

3. Include ample opportunity for teachers to recognize and make explicit their existing conceptions of the nature of science and mathematics and of the nature of learners and learning. The teachers should then be confronted with a variety of situations where their existing conceptions

do not fit with reality. Finally, teachers need to begin the process of reconstructing their former conceptions into ones that fit better with reality.

4. Give the teachers enough time to reconstruct their understanding of how they should teach science and mathematics. This reconstruction process also requires substantial support where discussion of emerging conceptions with others undergoing change is encouraged, where experiences are structured to facilitate the development of more accurate conceptions, and where the materials and psychological bolstering necessary for change are easily accessible.

5. Model effective science or mathematics education practices in teacher enhancement projects. In order for teachers to adopt new educational strategies, they must see them in practice and be able to assess their benefits. They are unlikely to become converts to constructivist instructional methods if they hear about them in a lecture rather than experience them first hand.

6. Give teachers the opportunity to practice what they learn in in-service education. Many hurdles inhibit the integration of new knowledge or instructional methods into one's classroom. Providing opportunities to apply new concepts or ideas can ease the adoption process. Teachers can benefit from practice during in-service programs and in follow-up activities designed to reinforce their outcomes.

7. Evaluate the progress and outcomes of teacher enhancement programs. Only by systematically assessing the operations and results of in-service initiatives can project staff learn from mistakes and improve the effectiveness of the programs they administer.

9.7 School Systems and Educational Administrators

Meaningful teacher enhancement requires the active support of educational leaders and the institutions they serve. Reform relies on the types of incentives and resources schools are willing to commit to the effort. School systems and academic leaders need to take three key steps in support of teacher enhancement:

1. It is important to acknowledge the key role teachers play in the educational reform process. Recognition of this reality means that schools should consult with teachers as they design new curricula, select textbooks and instructional equipment, and plan teacher enhancement initiatives. By treating teachers as true professionals, schools can count on them to become actively engaged in the reform of science and mathematics education.

2. Teachers must be empowered to implement reform in their classrooms. Schools that advocate reform must provide teachers with the time and resources necessary to restructure science and mathematics education. They need to encourage communication among teachers about curriculum innovations and, when appropriate, to provide teachers with new curricular materials and equipment, too. Likewise, schools should encourage teachers to take risks in their classrooms and question the status quo. By recognizing and rewarding teachers who experiment responsibly with innovative educational strategies, schools will weaken the grip of the traditional methods that often make science and mathematics education passive and uninspiring.

3. School districts should promote collaboration and team building. Teachers, principals, curriculum specialists, parents, and other relevant parties need to be included in the reform effort. Their different perspectives, expertise, and resources will serve to enhance the reform. Groups working together on matters of common concern can build momentum for reform more efficiently than can even the most effective teachers working alone.

9.8 Government Policy Makers and Funding Agencies

Strengthening science and mathematics education is a critical national priority. For this reason, government policy makers and public and private funding agencies have a major role to play in insuring that a vital teacher enhancement system promotes the professional growth and renewal of the nation's teaching force.

1. Policy makers need to recognize that teacher enhancement must be a continuous process. Teachers will always need to engage in professional development activities, just as physicians are required to do. Teachers must teach in an ever-changing environment in terms of the children, the content, the school, and the society, and they need to be prepared to meet these changing demands. Teacher enhancement programs need to be directed to develop mechanisms that will provide for continuous enhancement and not just be single, unconnected experiences.

2. Funding agencies should provide consistent, longer-term financial support for even one-time experiences. "Quicky" programs that try to "fix" teachers' deficiencies in one- or two-week workshops are likely to have negligible impact in a teacher's classroom. Support for longer term programs that work with teachers over a period of months or years are more likely to stimulate change. Quick fixes do not work any better in science and mathematics education than they do in other areas of life.

3. Educational testing programs designed to comply with demands for public accountability should not determine the nature of science and mathematics education. Government officials must recognize that tests

measuring retention of discrete factual knowledge do not adequately assess the development of genuine science literacy or numerical power. Achievement examinations used for accountability purposes should be consistent with the philosophy and goals of the reform movement in science and mathematics education.

4. Policy makers need to fund programs that recognize the complex issues involved in implementation of educational reform. Curricula, instructional methods, and assessments interact in complex ways, and actual implementation of reform is dependent on a variety of personal and situational issues. Teacher enhancement programs must be informed about these issues and require projects to use strategies that help to guarantee the implementation of reform.

5. Teacher enhancement programs supported by public funds should be evaluated on a regular basis. Just as routine evaluation plays a key role in individual teacher enhancement projects, it also helps to maintain quality control in large funding programs that subsidize in-service education for science and mathematics teachers. Teacher enhancement funding programs should not be continued because of tradition or because they appear to be "the right thing to do." Teacher enhancement programs should receive ongoing support because systematic evaluation efforts confirm that they have a positive impact on teacher behaviors and the educational process.

6. In addition to evaluation efforts, experimental research projects should be funded to allow us to understand the nature of teacher enhancement. For example, studies could be conducted to determine what are the most effective means of providing teacher enhancement, how implementation could be optimized, which components of teacher enhancement projects are essential and which are luxuries, and what theoretical framework explains the process most accurately.

9.9 Conclusion

This book presents a complex view of teacher enhancement. Conducting effective enhancement requires not only a specific knowledge of how to manage programs, but also an understanding of the context of education and curricula and attention to theory on the nature of learning. The ideas presented here include the notion of continual growth in education and the belief that mechanisms need to be put in place that will continue to foster change. Furthermore, the ideas presented indicate that change occurs on an individual basis. Each person needs to develop his or her own conceptual framework of the necessary reform and how it should be implemented. Teacher enhancement programs need to be designed that recognize this complexity and provide for the incorporation of committed individuals into the change process.